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ENGINEERING DATA ON NEW AEROSPACE STRUCTURAL MATERIALS

O. L. Deel, et al

Battelle Columbus Laboratories

Prepared for:

Air Force Materials Laboratory

September 1972

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ENGINEERING DATA ON NEW AEROSPACE STRUCTURAL MATERIALS

O. L. DEEL and H. MINDLIN

Battelle Columbus Laboratories

TECHNICAL REPORT AFML-TR-72-196
VOLUME I

SEPTEMBER 1972

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Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

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developed materials of interest to the usage, and then to provide "data sheet for these materials. The effort cover 17-4 PH (H900) ESR bar, Udimet 710 for T351 plate, and Ti-6Al-4V (DBHT) difference.	include tension, compression, shear, bend,

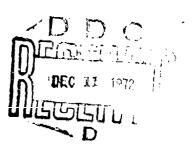
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O. L. Deel and H. Mindlin



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FOREWORD

This report was prepared by Battella's Columbus Laboratories, Celuss, Ohio, under Contract F33615-71-C-1262. This contract was performed under Froject No. 7381, "Materials Applications", Task No. 738106, "Engineering and 46.37 Data". The work was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Ease, Ohio, by Mr. Clayton Harmsworth (AFML/LAE), technical manager.

This final report covers work conducted from April, 1971, to July: 197.. In: report was submitted by the authors on August 9, 1972.

This technical report has been reviewed and is approved.

a Obertat A. Olevitch

Chief, Materials Engineering Branch Materials Support Division Air Force Materials Laboratory

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INTRODUCTION

The selection of materials to most effectively satisfy new environmental requirements and increased design load requirements for advanced Air Force weapons systems is of vital importance. A major difficulty that design engineers encounter, particularly for newly developed materials, materials processing, and product forms, is a lack of sufficient engineering data information to effectively evaluate the relative potential of these developments for a particular application.

In recognition of this need, the Air Force has sponsored several programs at Battelle's Columbus Laboratories to provide comparative engineering data for newly developed materials. The materials included in these evaluation programs were carefully selected to insure that they were either available or could become quickly available on request and that they would represent potentially attractive alloy projections for weapons system usage. The results of these programs have been published in four technical reports, AFML-TR-67-418, AFML-TR-68-211, AFML-TR-70-252, and AFML-TR-71-249.

This technical report is a result of the continuing effort to relieve the above situation and to stimulate interest in the use of newly developed alloys, or new processing techniques for older alloys, for advanced structures or propulsion systems.

The materials evaluated under this program are as follows:

- (1) 17-4-PH (H900) ESR Bar
- (2) Udimet /1) Forged Bar
- (3) 7050-T7E56 Hand Forging
- (4) 2214-T351 (Alcoa 417 Process) Plate
- (5) Ti-6Al-4V (DBHT) Diffusion Bonded Component.

The temper or heat-treat conditions selected for evaluation are described in each alloy section.

The program approach was, as on previous contracts, to search the published literature and to contact metal producers and derospace companies for any pertinent data. If very little pertinent information was available, a complete material evaluation was conducted. Upon completion of each material evaluation, a "data sheet" was issued to make the data immediately available to potential users rather than defer publication to the end of the contract term and the summary technical report. These data sheets are reproduced in Appendix III of this report.

Detailed information concerning the properties of interest, test techniques, and specimen types are contained in Appendices I and II of this report.

17-4 PH (1900) Bar (USR)

Material Description

This alloy is one of the family of precipitation hardening stainless steels which have found wide usage in aerospace, industrial, and commercial applications. The particular material used in this evaluation was produced by the Electroslag Remelting (ESR) process. In this process an electrode (in this case, air melted 17-4 PH) is melted in a resistance helted molten bath of flux contained in an open-bottomed water-cooled metal mold. The melted metal forms a pool beneath the flux bath and progressively solidifies forming an ingot which is continuously extracted from the mold.

The metal is refined and desulfurized by flux action and the microstructure is improved by controlled solidification.

The material used in this evaluation was a 3.3-inch-diameter bar from Heat 02298. Chemistry was as follows:

Chemical	
Composition	Percent
Carbon	0.04
Manganese	0.70
Silicon	0.41
Phosphorus	0.15
Sulfur	0.08
Chromium	15.9
Nickel	4.45
Copper	3.45
Colembium	0.23
lron	Balance

Processing and Heat Treating

All specimens were machined from the longitudinal direction, except for both longitudinal and transverse Charpy impact specimens, as shown in Figure 1. They were then heat treated at 900 F for 1 hour to Condition H900.

Test kesults

Tension. Results of longitudinal tests at room temperature, 400 F, 700 F, and 900 F are given in Table 1. Stress-strain curves at temperature are shown in Figure 2. Effect of temperature curves are presented in Figure 4.



FIGURE 1. SPECIMEN LAYOUT FOR 17-4 PH (H900) BAR (ESR)

8-38-4

Compression. Results of longitudinal tests at room temperature, 400 F, 700 F, and 900 F are given in Table II. Stress-strain and tangent-modulus curves are presented in Figure 3. Effect of temperature curves are shown in Figure 5.

Shear. Results of room temperature pin shear tests are given in Table III.

limpact. Charpy test results for longitudinal and transverse specimens at room temperature are given in Table IV.

Fracture Toughness. Slow-bend tests were conducted at room temperature. Results are given in Table V. The K_{ij} values obtained are considered valid K_{ij} numbers by existing ASTM standards.

Fatigue. Axial load fatigue tests results for unnotched and notched longitudinal specimens are given in Tables VI and VII. S-N curves are presented in Figures 6 and 7 for room temperature, 400 F, and 700 F.

Creep and Stress-Rupture. Results of tests on longitudinal specimens at 700 F, 900 F, and 1100 F are given in Table VIII. Log-stress versus log-time curves are shown in Figure 8.

Stress Corrosion. Six specimens were tested as described in the experimental procedures section of this report. No cracks or failures occurred in the 1000 hour test duration.

Thermal Expansion. The coefficient of thermal expansion for this alloy is 6.5×10^{-6} in/in/F for 68 F to 900 F.

Density. The density of this material is 0.282 lb/in3.

TABLE 1. TENSION TEST RESULTS TOWNERS OF THESE ARE (ESR)

Specimen Number	Ultimate Tensile Strength, ksi	0.2 percent Offset Yield Strength, ksi	Elongation in 2 inches, percent	Reduction in Area, percent	Tensile Modulus, 10° psi
		Room Tempe	rature		
111 112 113	201,4 195,8 194,4	189.6 184.2 182.9	16.2 18.0 17.2	50.0 45.6 48.2	28.5 29.2 28.3
		400 F	· •		
1L-4 i:,-5 1L-6	180.2 176.4 175.8	159.6 160.2 158.0	10.1 11.6 10.9	38.6 38.0 36.2	26.2 26.3 27.0
		700 F			
1L-7 1L-8 1L-9	160.0 162.8 158.3	142.6 147.6 144.8	9.9 10.2 9.7	38.6 31.2 34.9	24.0 24.4 23.6
		900 F	•		
1110 1111 1112	138.0 142.2 137.9	110.0 108.0 106.5	10.0 9.5 9.5	30.0 38.0 35,2	22.8 20.9 23.1

TABLE II. COMPRESSION TEST RESULTS FOR 17-4 PH (H900) BAR (ESR)

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, 10° psi
	Room Temperature	
2L-1	172.6	29.6 30.1
2L-2 2L-3	170.0 176.7	31.0
	400 F	
2L-4	147.6	27.0
2L-5 2L-6	150.0 146.2	27.4 26.2
	700 F	
217 218	138.6	25.1 24.0
218	138.6 141.2	24.9
	900 F	
2110	117.0	24.2
2111 2112	118.7 117.0	24.0 23.4

TABLE 111. SHEAR TEST RESULTS FOR 17-4 PH (H900) BAR (ESR)

Specimen Number	Ultimate Shear Strength, ksi
4L-1	117.0
4L-2	117.2
4L-3	117.0
4L-4	118.0

TABLE IV. IMPACT TEST RESULTS FOR 17-4 PH (H900) BAE (ESR)

Specimen Number	Energy, ft/1bs
Longitu	dinal
101,-1	20.8
10L-2	21.0
10L-3	28.0
10L-4	16.4
10L-5	23,9
Transv	erse
107-1	19,0
10T-2	15.2
10T-3	21.9
10T-4	24.7
10T-5	17.6

TABLE V. FRACTURE TOUGHNESS TEST RESULTS FOR 17-4 PH (H900) BAR (ESR)

4.5	1.80	45.1
4.5	1.81	50.4
4.5	1.87	49.0
	4.5	4.5 1.81

TABLE VI. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED 17-4 PH (H900) BAR (ESR)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-2	150.0	23,300
5 - 3	145.0	27,100
5 – 1	140.0	69, 900
5 -4	135.0	33,900
5 ~5	130.0	117,300
5 - 6	125.0	109,500
5-7	120.0	7,458,300
5-9	110.0	338,700
5-10	105.0	11,419,500 ^(a)
	400 F	
5-11	150.0	(b)
5-15	140,0	ĵ 00
5-13	135.0	19,700
5-12	130.0	33,400
5-14	125,0	146,100
5-16	120.0	37,700 ^(c)
5-17	120.0	1,327,100
5-28	100.0	5,137,100 _(a)
5-29	90.0	10,026,000 (a)
	<u>700 F</u>	
5-18	135.0	100
5-19	125,0	(b)
5-20	120.0	163,600
5-21	117.5	188,400
5-22	115.0	900
5 -23	113.5	193,000
5 - 24	110,0	88,000
5 - 25	100.0	2,191,000
5-26	90.0	2,300,600
5-27	80.0	4,821,900 (a)
5-30	70.0	10,019,670 ^(a)

⁽a) Did not fail.

⁽b) Failed on loading.

⁽c) Broke at thermocouple.

TABLE VII. ANIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (K = 3.0) 17-4 PH (H900) BAR (ESR)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-1	130.0	1,400
5-2	1.20.0	2,400
5 - 3	90.0	6,100
5-4	70.0	7,800
5-6	60.0	18,500
55	50.0	41,700
5-7	40.0	60,300
5-8	30.0	14,853,100 ^(a)
	400 F	
5-9	70.0	4,600
5-12	65.0	16,600
5-10	60.0	20,200
5-13	55.0	22,200
5-14	52.5	57,800
5-11	50.0	10,8 ² 7,600 (a)
	700 F	
5-1 5	70.0	1,900
5-16	65.0	4,000
5-17	60.0	7,300
5-18	55.0	v0a,e1
5-19	50,0	61 100
5-20	45.0	11,386,900 (a)

⁽a) Did not tail.

TABLE VIII. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR 17-4 PH (H900) BAR (ESR)

			į	, J & 1	Comment of the contract of the party of the contract of the co	The second secon	ation.	Initial	Rupture	Elongs tion	R. duction	Minima Cre 19
	50 %	11.0	4 10 C C	5	percent	4 4 2 4 3 4 3 4 3 4		Serein,	Lime,	in 2 kn.,	of Area,	
No.	ksi	, , ,	9.1	0.2	0.5	1.0	2.0	percent	I.d.	percini	rercent	percent/ar
,		00.0						 	On Loading	11.1	56.6	;
) (°	16.0	7007		1.4	45	800	3250(5)	1,341	625.8(a)	3.53	1	0,00041
01-5	077	00.	10	120	2900' ⁰ '	•		0.778	599.0(4)	1.078	!	0.000.087
ę.	100	000	0	0.7	در: در	7.11	22.5	687.0	34.8	14.1	51.9	0.065
) ()	9 C B	00t	0.1	7	8.	75	730	0.426	184.8	22.2	50.5	0.005.5
) (1)	, c	9006	ن ن ا	4.3	09	135	195	ა, 388	279.7	20.9	52.8	0.005
3-3	36	νo	57	250	000	i	•	0.133	641.7 ^(a)	0.674	!	6,00041
•	Ç	ć.	C	c c	,		7.0	0,382	16.8	34.1	63.4	0.23
3 r	o t) C	, c		, ,		542	0,297	95.7	39.3	7.66 .	C 025
. 47 1 1 1 1) ()	2011		2 24	17.7	115	76 7	0.137	521.1	40.7	79.8	0.0351
		1100	145	310	(a) 0551	į	;	0	648.8(a)	0.290	:	0.00621
, , ,	r ·	1100	Syl	310	0551		!	>		;		

(a) Test discontinued. (b) Estimate.

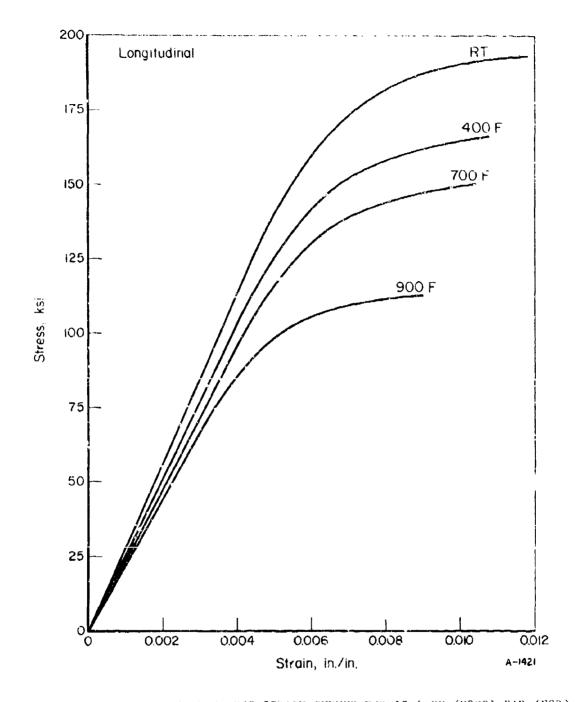
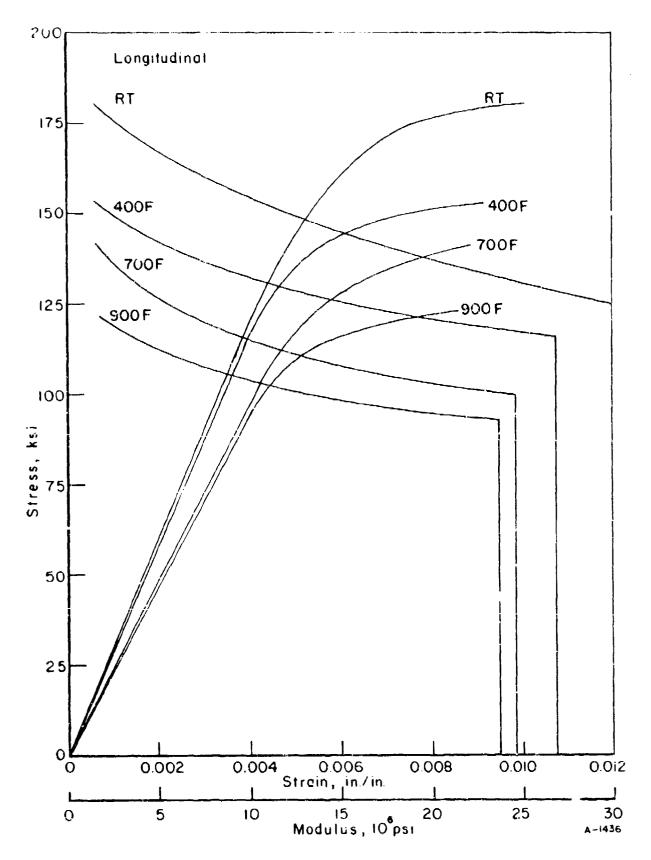


FIGURE 2. TYPICAL TENSILE STRESS-STRAIN CURVES FOR 17-4 PB (H900) BAR (ESE)



TIGURE 3. TYPICAL COMPRESSIVE STRESS-STRAID, AND TARGEDISMODULUS CURVES FOR 17-4 PH (H900) BAR (ESR)

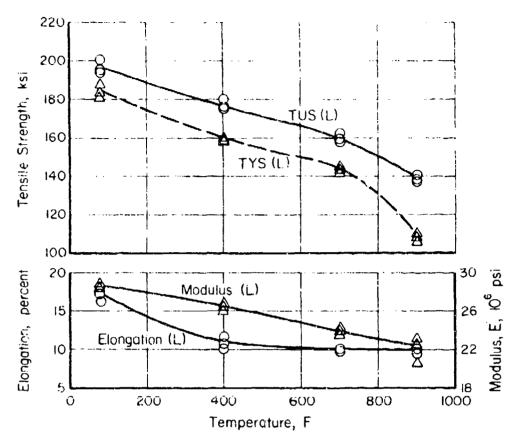


FIGURE 4. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 17-4 PH (H900) BAR (ESR)

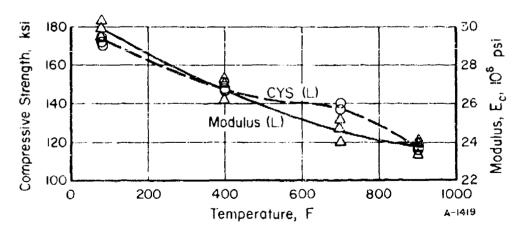


FIGURE 5. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 17-4 PH (H900) BAR (ESR)

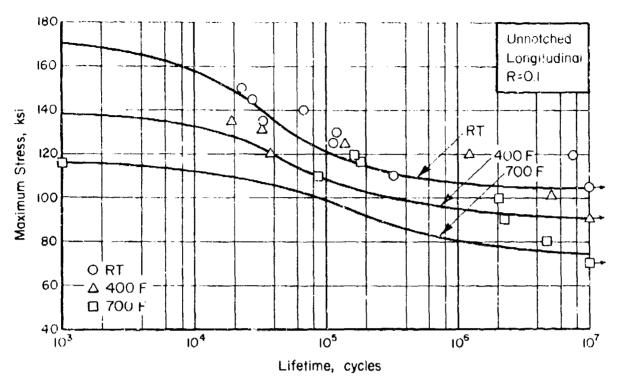
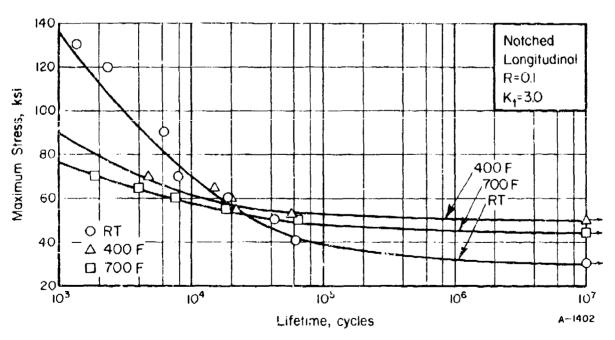
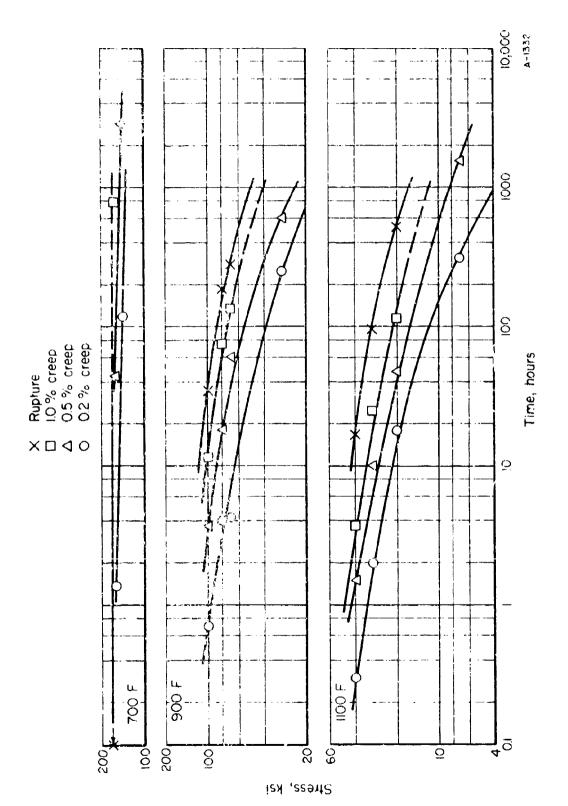


FIGURE 6. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED 17-4 PH (H900) BAR (ESR)



FICURE 7. ATT LOAD FATIGUE RESULTS FOR NOTCHED (1.0) 17-4 PH (H900) BAR (ESR)



STRESS-RUPIURE AND PLASTIC DEFORMATION CURVES FOR 17-4 PH (H900) BAR (ESR.) FIGURE 8.

Udimet 710 Forged Bar

Material Description

Udimet 710 was recently developed by Special Netals Corporation to fill the need for a jet engine turbine blading alloy, combining the high strength and stability characteristics of Udimet 700 with the corrosion and sulfidation resistance of 18% chromium alloys such as the older Udimet 500 and Waspaloy. The alloy is designed for use in either the wrought or cast form. Data generated at Special Netals from laboratory heats show it to have rupture strengths superior to Udimet 700, good oxidation and hot corrosion resistance and excellent phase stability after extended exposure to stress and temperature. Data are now being generated from production scale heats for both cast and wrought forms.

The material used for this evaluation was Special Metal Corporation Heat No. 8-2814. The alloy was obtained as 1.875 inch diameter bar with the following composition:

Chemical	
Composition	Percent
Carbon	0.07
Mangar-ese	0.10
Silicon	0.10
Chromium	18.0
Cobaít	14.8
lrou	0.14
Molybdenum	3.10
Tungscon	1.47
Titanium	4,88
Aluminum	2.51
Boron	0.018
Zirconium	0.04
Sulfur	0.003
Nickel	Balance

Processing and Heat Treating

Specimens were machined from the bar in the longitudinal direction as shown in Figure 9. Heat treating, as suggested by Special Metals, was as follows:

- (1) 2150 F for 4 hours, air cool,
- (2) 1975 F for 4 hours, air cool,
- (3) 1550 F for 24 hours, air cool,
- (4) 1400 F for 16 hours, air cool.

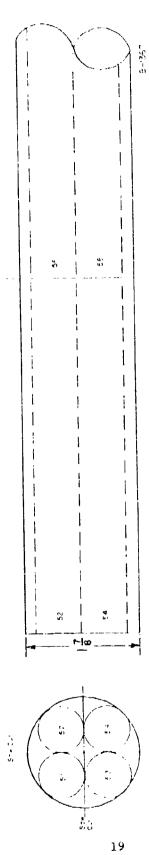


FIGURE 9. SPECIMEN LAYOUT FOR UDIMET 710 FORGED BAR

Test Results

Tension. Test results for longitudinal specimens at room temperature, 800 F, 1200 F, and 1800 F are given in Table IX. Stress-strain curves at temperature are shown in Figure 11. Effect of temperature curves are shown in Figure 12.

Compression. Test results for longitudinal specimens at room temperature, 800 F, 1200 F, and 1800 F are given in Table X. Stress-strain and tangent-modulus curves are shown in Figure 10. Effect of temperature curves are shown in Figure 13.

Shear. Test results are given in Table XI for longitudinal pin shear specimens.

lmpact. Charpy test results for longitudinal specimens at room temperature are given in Table XII.

Fracture Toughness. Slow-bend fracture toughness tests were conducted at room temperature. Test results are given in Table XIII. Since the size ratio, 2.5 $(K_Q/TYS)^2$, was greater than both the specimen thickness and crack length in all tests, the K_Q values are not considered valid K_{IC} numbers by existing ASTM criteria.

Fatigue. Axial load fatigue test results for unnotebed and notehed longitudinal specimens at room temperature, 800 F, and 1200 F are given in Tables XIV and XV. S-N curves are presented in Figures 14 and 15.

Creep and Stress Rupture. Test results at 1000 F, 1400 F, and 1800 F are given i. Table XVI. Log-stress versus log-time curves are presented in Figure 16.

Stress Corrosion. Tests were conducted as described in the experimental procedures section of this report. No failures or cracks occurred in the 1000-hour test duration.

Thermal Expansion. The coefficient of thermal expansion for this allow is 8.7×10^{-6} in./F from 70 F to 1400 F.

Density. The density of this material is 0.292 lb/in. 3.

TABLE IX. TENSION TEST RESULTS FOR UDINET 710 FORGED BAR

Specimen Number	Ultimate Tensile Strength, ksi	0.2 percent Offset Yield Strength, ksi	Elongation in 2 inches, percent	Reduction in Area, percent	Tensile Modulus, 10° psi
		Room Tempe	rature		
111 112 113	177.0 178.0 178.0	138.0 139.0 137.0	7.2 7.7 6.7	7.0 9.6 9.5	30.9 27.9 28.9
		800 I	· -		
11,-4 11,-5 11,-0	167.8 167.8 162.6	123.2 123.1 122.2	7.6 7.6 7.6	9.6 9.0 9.0	24.3 23.9 24.4
		1200	<u>F</u>		
11/ 1L-8 1L-9	183.0 177.6 191.0	118.5 123.1 127.1	16.0 13.0 17.0	13.6 16.1 14.0	21,4 20,3 20,9
		1800	<u>F</u>		
1L-10 1L-11 1L-12	53.4 56.5 55.0	38.2 35.9 36.9	29.8 30.0 30.2	32.0 37.0 37.0	18.6 20.0 17.9

TABLE X. COMPRESSION TEST RESULTS FOR UDINET 710 FORGED BAR

	0.2 Percent	Compression
Specimen	Offset Yield	Modulus,
Number	Strength, ksi	10° psi
	Room Temperature	
211	150.0	30.9
2L-2	151.0	31.0
2L-3	148.0	30.0
	800 F	
2L-4	127.0	26.0
2L-5	127.0	25.0
2L-6	127.0	25.6
	1200 F	
2L-7	118.0	23.3
2L-8	119.0	22 .1
2L-9	118.5	22.0
	1800 F	
2L-10	37.0	18.6
2L-11	38.0	18.0
2L-12	37.0	18.0

TABLE XI. SHEAR TEST RESULTS FOR UDINET 710 FORGED BAR AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear Strength, ksi
411	123.1
411 412	127.2
413	125.1
414	129.7

TABLE XII. IMPACT TEST RESULTS FOR UDIMET 710 FORGED BAR

Specimen Number	Energy ft 1bs
101-1	29.5
104-2	26.0
1013	26.0
1014	25.0
10L-5	27.0
1016	33.0

TABLE XIII. FRACTURE TOUGHNESS TEST RESULTS FOR UDINET 710 FORCED BAR

Specimen Number	W, inches	a, inches	T, inches	P, 1bs	Span, inches	$f(\frac{\partial}{w})$	Ķ _Q (a)
1	1.500	.750	.750	9,250	4.5	2.66	80.5
2	1.502	.765	.748	9,000	4.5	2.74	80.7
3	1.500	.749	.749	9,400	4,5	2.66	81.7
4	1.502	.762	.749	8,400	4.5	2.72	74.8

⁽a) Candidate fracture toughness values, K_Q , are invalid as K_{1c} values since a, $T_{+} + 2.5 \; \left(\frac{K_Q}{TYS}\right)^{\circ}$.

TABLE XIV. AXIAL LOA) FATIGUE TEST RESULTS FOR UNNOTCHED UDIMET 710 FORGED BAR

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperatur	<u>·e</u>
5-4	135.0	60,130
5-1	125.0	86,250
5-5	120.0	147,536
5-2	115.0	164,310
5-27	112.5	274,000
5-6	110.0	435,110
5-28	107.5	1,247,000
5-3	105.0	6,610,600
5-7	100.0	12,282,720 ^(a)
	800 F	
5-17	110.0	17,000
5-16	100.0	107,900
5-13	95.0	125,200
5-19	90.0	82,300
5 ~ 20	85.0	173,200
5-21	80.0	197,300
5-22	75.0	838,600
5-23	70.0	977,700
<u>- 24</u>	0.د	739,500
5-25	55.0	6,488,000
5 – 26	45.0	16,419,400(a)
	<u>1200 F</u>	
5-9	120.0	100
5.40	100.0	86,100
5-11	95.0	119,300
5-12	90.0	284,700
5-13	85.0	122,200
5-14	80.0	1,626,200
5 – 29	77.5	10,489,900(a
5-15	75.0	10,474,400 ^{(a}

⁽a) Did not fail.

TABLE NY. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (E. \pm 5.0) USIMET 710 FORGED BAR

Specimen Number	Maximom Stress, ksi	Lifetime, cycles
	Room Temperature	
5 – 1	100.0	20,270
5 - 2	90.0	29,660
5 - 3	0,03	51,170
5 -4	77.0	67,310
5 - 5	60.0	114,890
5 -8	55.0	132,430
5 - 6	50.0	366,160
57	40.0	793,110
5 – 10	35.0	1,791,800
5 - 9	30.0	2,693,800
5-11	25.0	11,458,100 (a
	<u>800 F</u>	
5 - 18	65.0	13,700
5-19	60.0	20,600
5-20	55.0	21,500
521	50.0	73,800
5-22	45.0	134,800
5-23	40.0	6,707,000
5 - 24	35.0	680,100
5 -25	30.0	10,013,600 ^{(a}
5-26	27.5	5,577,200
	1200 F	
5 - 17	65.0	5,200
5-12	60.0	7,600
5-15	55. v	9,800
5-13	50.0	42,100
5-16	45.0	62 900
5 - 27	42.5	10.321.900 ^{(a}
5 - 14	4().()	10,043,700 ^{(a}

⁽a) Did not fail.

TABLE XVI, SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR UDDET 710 FORCEL BAR

3-4 18: 18: 18: 18: 18: 18: 18: 18: 18: 18:	1.	H	d. G.	ted Creep percont	Deformati	, no	Initial Strain,	Ruprere Tire,	Elengation in 2 in.,	Reduction of Area,	Creck Creck Cate,
181 175 167 150 120 70 70		0.1	0.2	0.5	1.0	2.0	percent	hr	percent	percent	percent, hr
175 157 150 120 70 70	1030	•	i		;	ł	i	Or. Loading	25.3	27.6	;
157 150 120 90 70 40	1000	0.03	٥,5		0.42	г .	15.41	16.7	34.1	32.9	0.1
150 120 90 70 40	1000	0.05	0.03		1.5	5.0	9.367	100.3	7.96	27.4	0.15
120	1000	0.10	0.3	3.5	14.5	95	5.284	121.3 ^(a)	8.360	;	0.015
900 207	0001	100	1500 ^(b)		;	:	1.297	957.6 ^(a)	1.478	į	0.00001
0.7	1400	0.02	0.03	0.04	0.15	0.45		2.5		34.9	2.7
07	1400	0.08	0.18	0.65	2.5	10		55.7		50.0	0.12
	1400	20	06	420	1109	2450 ^(t)	0.241	1095.7 ^(a)	1,237	:	0.00074
20	1800	0.05	3,	0.10	0.30		0.274	0.6	23.0	54.5	a ci
3-11 2 1	1800	3.0 14	28.	62	45 115	190	0.011	955.8	41.4	42.0	0.007

⁽a) Test discontinued.(b) Estimate.

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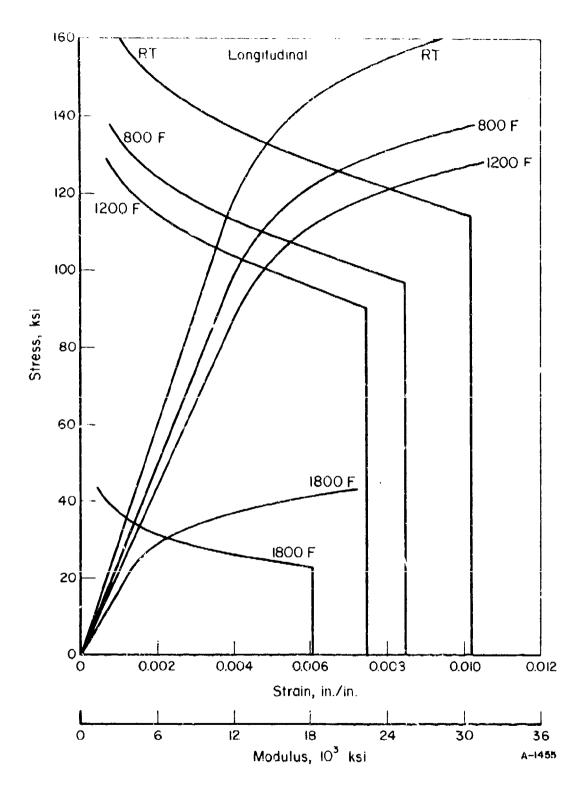


FIGURE 10. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS GURVES FOR UDIMET 710 FORGED BAR (LONGITUDINAL)

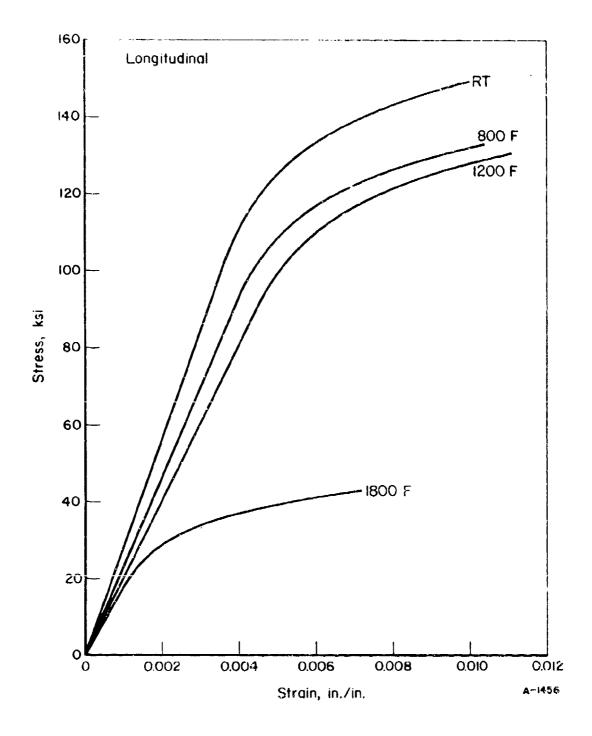


FIGURE 11. TYPICAL TENSILE STRESS-STRAIN CURVES FOR UDIMET 710 FORGED BAR (LONGITUDINAL)

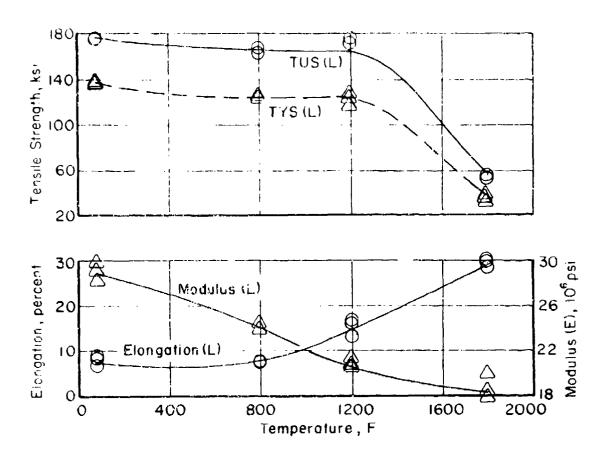


FIGURE 12. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF UDIMET 710 FORGED BAR

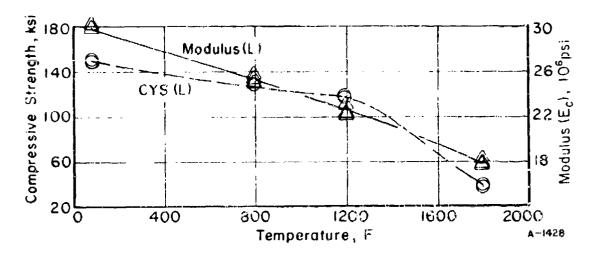


FIGURE 13. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF UDINET 710 FORGED EAR.

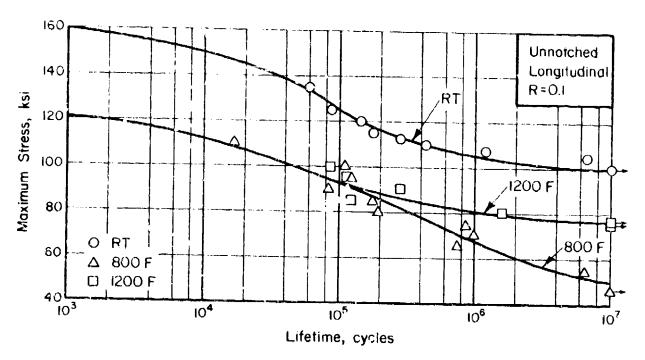


FIGURE 14. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED UDIMET 710 FORGED BAR

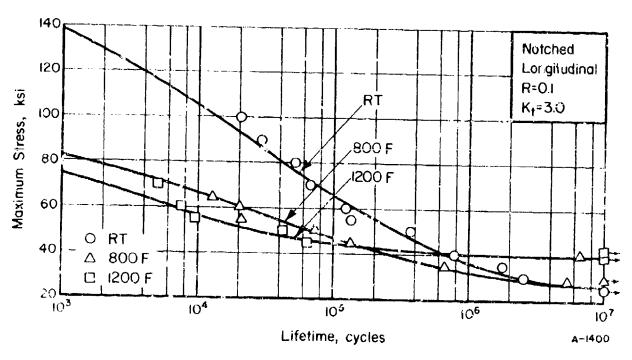


FIGURE 15. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED $(K_{_{1}} = 3.0)$ UDIMET 710 FORGED BAR

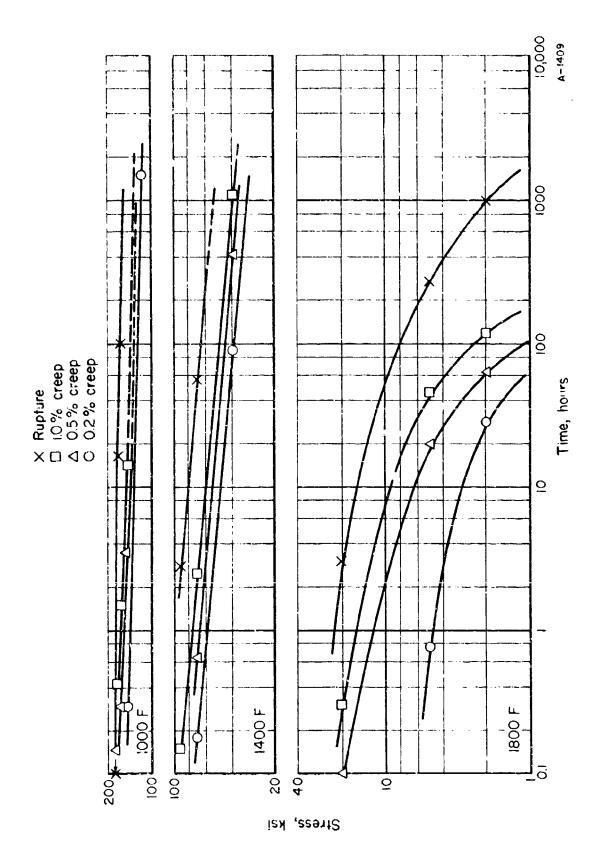


FIGURE 16. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR UDIMET 710 FORCED BAR

7050-T7E56 Hand Porging

Material Description

Alloy 7050 is an Al-Zn-Mg-Cu alloy developed by the Alcoa Research Laboratories supported by the Naval Air Systems Command and the Air Force Materials Laboratory. When heat treated and aged to the -T73 temper, thick 7050 plate and hand forgings exhibit strengths equal to or exceeding those of 7079-T6XX products combined with improved fracture toughness and a high resistance to exicliatiation and stress-corrosion cracking. The alloy differs from conventional 7XXX series aluminum alloys in that zirconium is added and chromium and manganese are restricted in order to minimize quench sensitivity.

The material used for this evaluation was a 5-inch by 10-inch by 5-foot hand torging produced within the following composition limits:

Chemical Composition	Percent
Copper	2.0 to 2.8
Iron	0.15 max
Silicon	0.12 max
Manganese	0.10 max
Magnesium	1.9 to 2.6
Zinc	5.7 to 6.7
Chromium	0.04 max
Tiranium	0.06 max
Aluminum	Balance

Processing and Heat Treating

The specimens were tested in the as-received -T7E56 temper.

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FIGURE 17. SPECIMEN LATOUT FOR 7050-17556 HAND FORGING

Test Results

Tension. Results of tests in the longitudinal and transverse directions at room temperature, 250 F, 350 F, and 500 F are given in Table XVII. Short transverse tests were not conducted at elevated temperatures. Stress-strain curves at temperature are presented in Figures 18 and 19. Effect of temperature curves are shown in Figure 22.

Compression. Results of tests in both the longitudinal and transverse directions at room temperature, 250 F, 350 F, and 500 F are given in Table XVIII. Stress-strain and tangent-modulus curves at temperature are presented in Figures 20 and 21. Effect of temperature curves are shown in Figure 23.

Shear. Pin shear test results for longitudinal and transverse specimens at room temperature are given in Table XIX.

<u>Impact</u>, Charpy test results for longitudinal and transverse specimens at room temperature are given in Table XX.

Fracture Toughness. Results of slow bend tests for longitudinal and transverse specimens are given in Table XXI. The transverse tests fall within the size ratio, 2.5 $\left(K_{Q}/\text{TYS}\right)^{2}$, and the K_{Q} values are considered valid. The longitudinal tests do not meet this requirement and are not considered valid by existing ASTM criteria.

Fatigue. Axial-load fatigue tests were conducted on transverse specimens at room temperature, 250 F, and 350 F. Tabular test results are given in Tables XXII and XXIII. S-N curves are shown in Figures 24 and 25.

Creep and Stress Rupture. Results of transverse tests at 250 F, 350 F, and 500 F are given in Table XXIV. Log-stress versus log-time curves are presented in Figure 26.

Stress Corrosion. Tests were conducted as described in the experimental procedures section of this report. No failures or cracks occurred in the 1000-hour test duration.

Thermal Expansion. The coefficient of thermal expansion for this allow is 12.8 x 10^{-6} in./in./F for 68 F to 212 F.

Density. The density value for X7050 is 0.102 lb/in. 3.

TABLE XVII. TENSION TEST RESULTS FOR 7050-T7E56 HAND FORGING

Specimen No.	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ks1	Elongation in 2 inches, percent	Reduction in Area, percent	Tensile Modulus, 10 ⁶ psi
		Longitudinal at	Room Temperatu	re	
lL-1	74-4	65.7	15.0	38.8	10.2
1L-2	73.7	63.4	15.0	38.1	9.9
1L-3	73.2	62.7	16.0	40.6	9.7
		Transverse at 1	Room Temperatur	<u>e</u>	
1T-1	74.0	64.4	9.0	13.0	9.9
1T-2	69.9	60.7	4.5	5.4	9.9
1T-3	69.4	61.2	3.5	5.1	9.9
	Sh	ort Transverse	at Room Tempera	ture	
1\$T-1	70.4	56.7	6.0	7.0	9.6
1ST-2	71.8	58.3	5.5	6.0	9.9
1ST-3	74.0	61.7	7.5	10,6	9.8
		Longitudin	al at 250 F		
1L-4	58.1	56.5	14.0	48.0	9.5
1L-5	56.4	54.5	21.0	52.1	9.7
1L-6	57.4	55.2	13.5	43.6	9.3
		Transvers	e at 250 F		
1T-4	57.3	55.7	22.0	54,0	9.4
1T-5	59.0	57.1	13.0	31,4	9.6
1T-6	56.0	52.8	12,5	21.2	9.3
		Longitudin	al at 350 F		
1L-7	47.4	46.7	15.0	62.7	8.3
1L-8	45.9	44.8	17.0	60.7	8.3
1L-9	48.0	47.4	14.0	62.2	8.4

TABLE XVII, (Continued)

Specimen	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Reduction in Area, percent	Tensile Modulus, 10 ⁶ psi
		Transvers	e at 350 F		
1T-7 1T-8 1T-9	44.2 45.9 46.4	42.8 44.3 44.3	18.5 15.0 14.5	58.0 44.2 37.8	8.9 8.1 8.2
		Longitudir	nal at 500 F		
1L-10 1L-11 1L-12	18.7 19.9 17.2	18.4 19.7 17.0	23.0 24.5 38.5	72.4 85.5 89.5	8.8 7.8 8.3
		Transvers	e at 500 F		
1T-10 1T-11 1T-12	19.7 19.3 19.2	18.7 19.0 18.5	23.5 27.0 25.0	80.2 84.6 77.6	7.8 8.3 7.6

TABLE XVIII. COMPRESSION TEST RESULTS FOR 7050-T7E56 HAND FORGING

181-142-763 1-7-4-		i i maaa kesa a keesa
Specimen No.	0.2 Percent Offset Yield Strength, ksi	Compressive Modulus, 10 ⁶ psi
	Longitudinal at Room Tempera	ture
211	69.4	10.5
21 - 2	71.4	10.9
2L-3	64.8	10.7
	Transverse at Room Temperat	ure
2T-1	65.3	12.2
2T-2	66.3	11.0
2T-3	65.3	11.0
	Longitudinal at 250 F	
2L-4	60.7	9.9
2L-5	62.3	10.1
216	60.9	9.8
	Transverse at 250 F	
2T-4	57.6	9.3
2T-5	59.3	9.9
2T-6	59.8	9.8
	Longitudinal at 350 F	
2L-7	51.2	9.3
2L-8	50.0	9.1
2L-9	50.1	9.2
	Transverse at 350 F	
2T-7	49.4	9.0
2T-8	49.6	9.4
2T-9	49.6	8.9

TABLE XVIII, (Continued)

Specimen	u.2 Percent Offset Yield Strength, ksi	Compressive Modulus, 10 ⁶ psi
-	Longitudinal at 500 F	
2L-10	20.7	7.6
2L-11 2L-12	21.5 21.5	6.7 7.5
	500 7	
	Transverse at 500 F	
2T-10	20.8	6.6
2T-11	21.5	6.6
2T-12	22.2	7.9

TABLE XIX. SHEAR TEST RESULTS FOR 7050-T7E56 HAND FORGING AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear Strength, ksi
	Longitudinal
411	41.3
412	42.5
4L-3	44.6
4L-4	43,6
	Transverse
4T-1	40.5
4T-2	40.0
4T-3	42.8
4T-4	43.1

TABLE XX. IMPACT TEST RESULTS
FOR 7050-T7E56
HAND FORGING AT
ROOM TEMPERATURE

Specimen No.	Energy, ft-1b
Longitu	udinal
10L-1	15.0
10L-2	7.0
10L-3	1.3.5
10L-4	8.0
10L-5	10.0
10L-6	14.5
Trans	verse
10T-1	2.0
10 T -2	2.0
10T-3	2.0
10T-4	2.0
1 0T-5	2.0
10 T -6	2.5

TABLE XXI. FRACTURE TOUGHNESS TEST RESULTS FOR 7050-T7E56 HAND FORGING

Specimen Number	W, inches	a, inches	T, inches	P, 1bs	Span, inches	$f(\frac{a}{w})$	$\kappa_{ m Q}$
			Transvei	rse			
21	1.501	.837	.750	1,750	6	3,2	24.6
34.	1.502	.863	.751	2,000	6	3.4	29.8
4T	1.502	.875	. 750	2,200	6	3.5	33.8
1 f	1,502	.837	.751	1,940	6	3.2	27.2
			Longitud	Lual			
61.	1,501	.861	.751	3,800	b	3.4	56.6
8L	1,502	.896	. 750	4,000	Ó	3.7	64.8
51,	1.500	.859	.750	3,510	6	3.4	52.2
71.	1,501	.898	.750	4,700	6	3.7	76.8

⁽a) Candidate fracture Loughness values, $\mathbf{K}_{\mathbf{Q}},$ are valid valid $\mathbf{K}_{\mathbf{1e}}$ values.

⁽b) Candidate fracture toughness values, K_Q , are invalid as K_r values since a, T, <2.5 $\left(\frac{K_Q}{TYS}\right)^2$.

TABLE XXII. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED 7050-T7E56 HAND FORGING (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Liferime cycles
	Room Temperature	The same and the s
5 - 2	55.0	36,800
5 - 23	52.5	200
5-1	50.0	39,630
5-3	45.0	80,380
5-21	42.5	11,500
5-4	40.0	248,480
5-22	37.5	258,000
5-5	35.0	393 210
5-24	32.5	405,000 (a
5-6	30.0	12,465,500 ^{(a}
	250 F	
5 - 7	55.0	100
5-8	50.0	117
5-12	40.0	20,600
5-9	35.0	36,590
5-10	30.0	76,480
5-11	25.0	2 725 100
5-26	22.5	10.137.580 ^{ta}
5-13	20.0	11,369,800 ^{(a}
	350 F	
5-14	40.0	100
5-20	40.0	10,100
5-17	35.0	16,650
5-15	30.0	50,670
5-16	25.0	122,250
5-18	20.0	121,930
5-25	17.5	20,713,500 (a
5-19	15.0	10,167,600 (a

⁽a) Did not tail.

TABLE XXIII. AXEAL LOAD FATIGUE TEST RESULTS FOR NOTCHED ($\kappa_c = 3.0$) 7050-T7E56 HAND FORGING (TRANSVERSE)

Specimen Number	Maximom Stress, ksi	hifetime, cycles
	Room Temperature	1
5-1	35.0	15,120
5 - 2	30.0	22,380
5-3	25.0	36,300
5-21	22.5	57,500
5-4	20.0	170,130
5-20	17.5	195,100
5-5	15.0	553 750
3 - 22	12.5	12 753 700 ^{(a}
5-6	10.0	10,781,080 (a
	250 F	
5-8	30.0	19,060
5 -23	27.5	214,800
5 - 7	25.0	185,550
5 - 24	22.5	214,800
5-9	20.0	272,550
5-11	1/.5	191,680
5-10	15.0	788,020
5 - 12	13.5	10,622,140 (a
	350 F	
513	30.0	10,860
5-14	25.0	39,200
5-15	22.5	29,460
5-16	20.0	72,910
5-17	17.5	267,530
5-18	15.0	160,430
5-25	15.0	1 161 700
5-19	13.5	12,207,520 (a

⁽a) Did not fail.

SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR 7050-T7E55 HAND FORGING (TRANSVERSE) TABLE XXIV.

				to Indicat	Hours to Indicated Green Deformation,	17400000	, 14	Instint Strain	01 - 01 (4 0 - 01 (4 0 - 01 (4	El mestion in 2 in.	Reduction of Area,	Cre.p Sate.
Spectaers No.	hectmen stress,		0.1	3.2	0.5	1.0	2.0	percent	.f3	persent	percent	percent/ar
3-1			0,11	0.35	1.7	4.7	;	0.677	18.3	12.1	32.7	0,15
3-3	707	250	10	75	355	545	:	0.422	558.4	7.7	0.4	
3-10	35	250	208	805	2570(5)	;	;	0,389	863,4(4)	0.600	:	6.363.7
									;		τ	,
3-5	25	350	3.1	8 .3	27	:	:	0.289	50.2	14.૯ ૦.૦	00	0,00° r
3-5	15	354	20	125	300	977	582	0.107	668.4	φ. ς γ. ς	3.54	0.000:4
	,,	350	620	1000(5)	:	1 1	;	0.185	765.1(4)		:	31000
1117	;	}										
,	,	5.30	7 0	1.3	4.9	15,6	26.8	0.122	48.2	31,1	68.3	0.052
, c	· v	900	· c	12	34	75	128	0.167	229.6	13.3	47.1	0.0033
0 I I	4.5	200	20 20	9	180	265	390	6.078	691.5	12.6	35.0	0.005
, c		500	\$	80	550 ^(b)	:	;	0.000	167.1(a)	6.348	:	0,0055
2	,))		(4)					(a)			0.00.053
3-9	1.5	500	1550	3450/2/		:	;	0	905.8	, ac.	:	0.00000

(a) Test discontinued.(b) Estimate.

A second

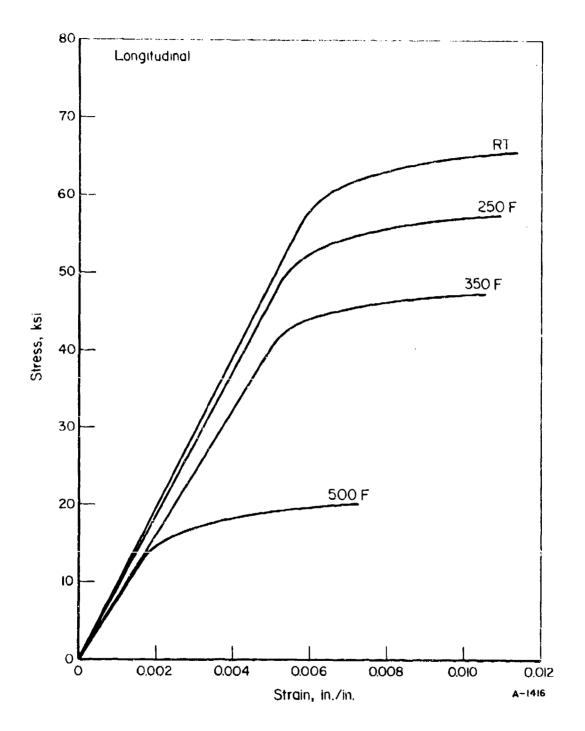


FIGURE 18. TYPICAL TENSILE STRESS-STRAIN CURVES FOR 7050-T7E56 HAND FORGING (LONGITUDINAL)

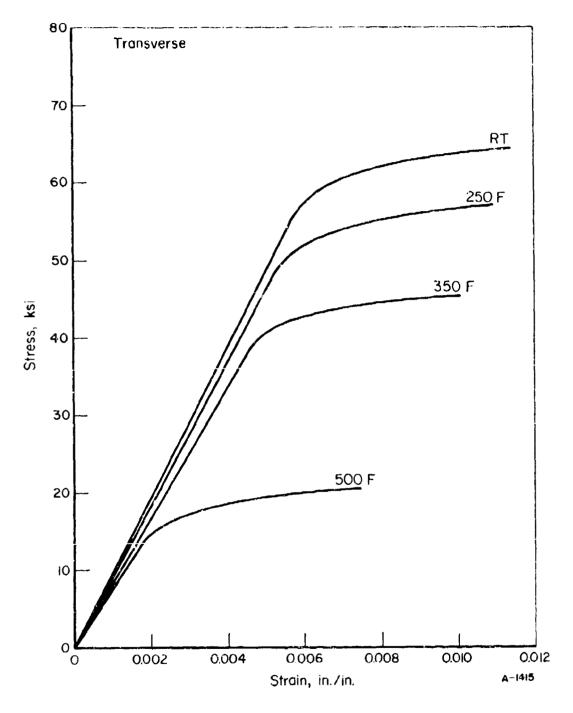


FIGURE 19. TYPICAL TENSILE STRESS-STRAIN CURVES FOR 7050-T7E56 HAND FORGING (TRANSVERSE)

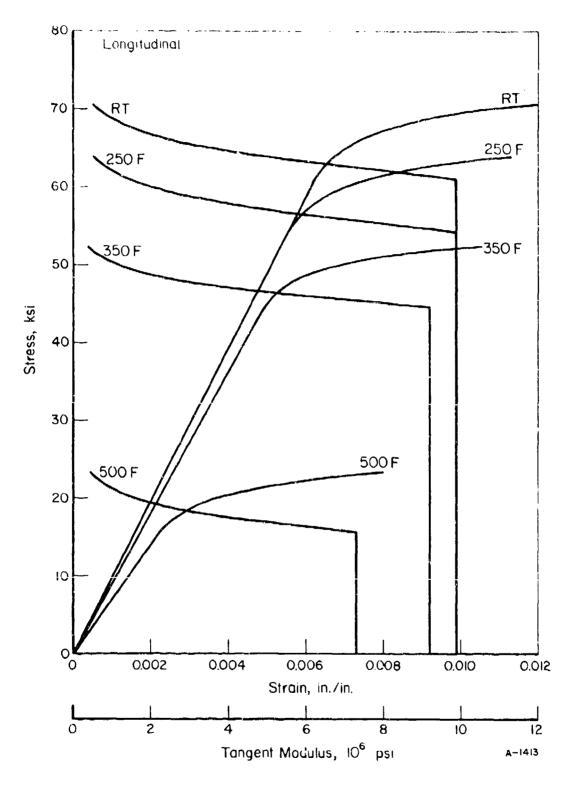


FIGURE 20. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR 7050-T7E56 HAND FORGING (LONGITUDINAL)

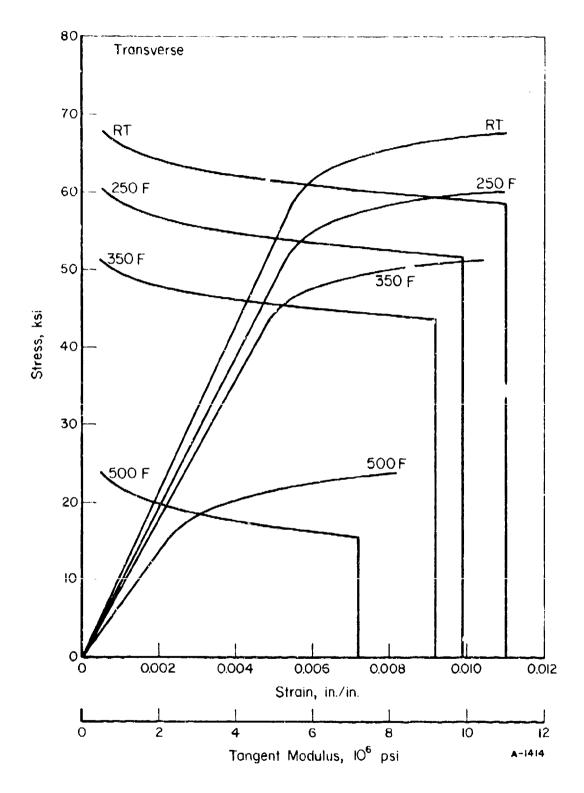


FIGURE 21. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR 7050-T7E56 HAND FORGING (TRANSVERSE)

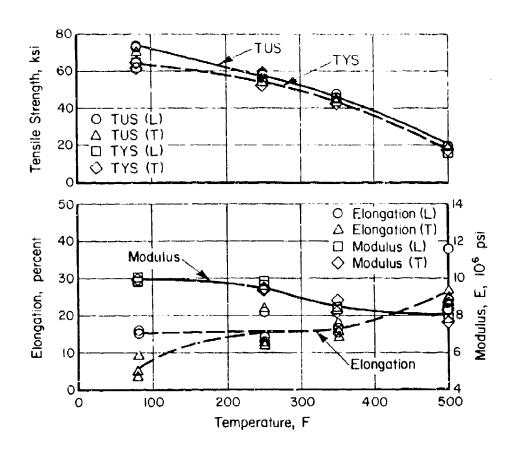


FIGURE 22. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7050-T7E56 HAND FORGING

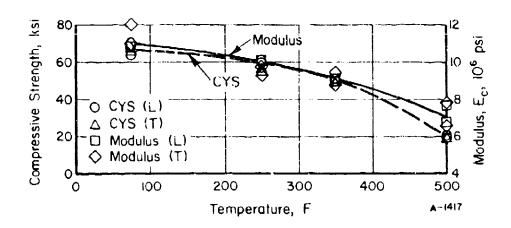


FIGURE 23. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7050-T7E56 HAND FORGING

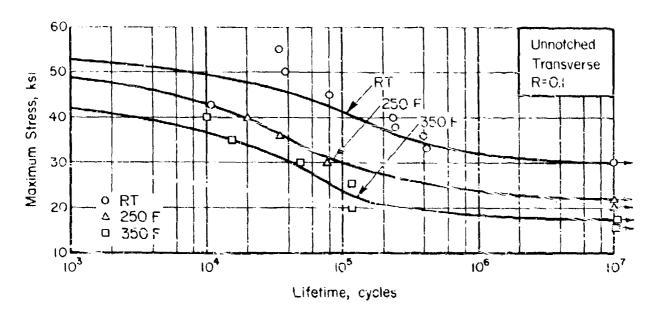


FIGURE 24. AXIAL-LOAD FATIGUE RESULTS FOR UNMOTCHED 7050-T/656 HAND FORGING

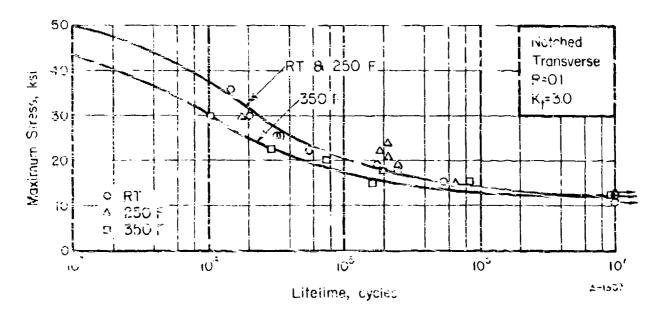
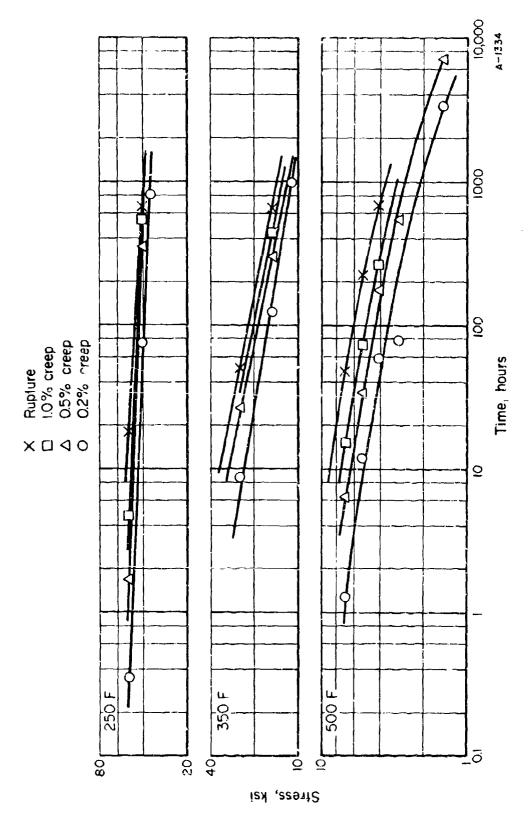


FIGURE 25. AXIAI-LOAD FATIGOD PESULTS FOR NOTCHED ($K_{\rm L}=3.0$) $7050\text{-}\mathrm{T7E56}$ HALD FORGING



STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7050-T7E56 HAND FORGING (TRANSVERSE) FIGURE 26.

2214-T351 Plate (Alcoa 417 Process)

Material Description

Alloy 2214 is a high-purity version of 2014 with closer controls on iron and silicon (Alcoa 417 process). The Alcoa 417 process, which utilizes only hot rolling and special controls during all stages of fabrication, is a more economic means for achieving the required properties without adversely influencing the overall engineering characteristics of the material. The material used in this evaluation was obtained from Alcoa as a 2-1/4-inch-thick plate within the following composition limits:

Chemical Composition	Percent
Silicon	0.50 to 1.2
Iron	0.3 max
Copper	3.9 to 5.0
Manganese	0.40 to 1.2
Magnesium	0.20 to 0.80
Chromium	0.10 max
Zinc	0.25 max
Titanium	0.15
Others	0.15 max
Aluminum	Balance

Processing and Heat Treating

The specimen layout for 2214 is shown in Figure 27. Specimens were tested in the as-received -T351 temper.

Test Results

Tension. Results of longitudinal and transverse tests at room temperature, $750 \, \text{F}$, $350 \, \text{F}$, and $500 \, \text{F}$ are given in Table XXV. Stress-strain curves at temperature are presented in Figures 28 and 29. Effect of temperature curves are snown in Figure 32.

			8-130A
		21.15	
		2-2 .2-5 Coms 2-16, 2-19	
	66 F.	10.0 St.	
	Froc. Tough		
	63.	1.6 1.9	-l i
600JT P 20		# 6 F. B	
2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2	35 3 333 335 315 315 315 315 315 315 315	ILS Tensile	11
			-1 1
60 80 90 90 90 90 90 90 90 90 90 90 90 90 90		57 515 523 533 547 555 563 112 11.2 11.4	
φ			-
7		, No.	

FIGURE 27. SPICINEN LAYOUT FOR 2214-T351 PLATE

Compression. Results of longitudinal and transverse tests at room temperature, 250 F, 350 F, and 500 F are given in Table XXVI. Stress-strain and tangent modulus curves at temperature are presented in Figures 30 and 31. Effect of temperature curves are shown in Figure 33.

Shear. Pin shear test results for longitudinal and transverse specimens at room temperature are given in Table XXVII.

Impact. Charpy test results for longitudinal and transverse specimens are given in Table XXVIII.

Fracture Toughness. Slow bend tests were conducted on longitudinal and transverse specimens at roo; temperature. The size ratio, 2.5 $(K_Q/TYS)^2$, was greater than both the specimen thickness and crack length in all tests; therefore, the K_Q values given in the table are not considered valid K_{I_Q} values by existing ASTM criteria. These data are shown in Table XXIX.

Fatigue. Axial-load fatigue test results for transverse specimens, both unnotched and notched, at room temperature, 250 F, and 350 F are given in Tables XXX and XXXI. S-N curves are presented in Figures 34 and 35.

Creep and Stress Rupture. Results of transverse specimen tests at 250 F, 350 F, and 500 F are given in Table XXXII. Log-stress versus log-time curves are presented in Figure 36.

Stress Corrosion. Tests were conducted as described in the experimental procedures section of this report. No failures or cracks occurred in the 1000-hour test duration.

Thermal Expansion. The coefficient of thermal expansion for this allow is 13.5 x $\frac{10^{-6} \text{ in./in./F}}{10^{-6} \text{ for } 68 \text{ F}}$ to 500 F.

Densi y. The density of this material is 0.101 lb/in. 3.

TABLE XMV. TENSION TEST RESULTS FOR 2214-T351 PLATE

Specim e n No.	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Reduction in Area, percent	Tensile Modulus 10 ⁶ psi
		Longitudinal at	Room Temperatu	<u>re</u>	
1L-1	65.2	46.9	24.0	34.7	10.4
1L-2	64.7	46.5	24.0	35.7	10.5
1L-3	64.9	46.9	23.5	32.1	10.5
		Transverse at 1	Room Temperatur	<u>e</u>	
1T-1	66.0	42.3	20.5	28.5	10.5
1T-2	65.9	43.5	20.5	27.7	10.7
1T-3	66.0	42.3	22.0	26.7	10,4
		Longitudin	el at 250 F		
1L-4	56.0	42.0	20.0	34.0	10.0
1L-5	56.0	41.7	24.0	48.0	9.8
1L-6	56.4	41.6	23.0	37.0	9.8
		Transvers	e at 250 F		
1T-4	57.0	39.2	28.5	31.4	9.7
1T-5	56.4	38.2	21.0	34.5	9.6
1T-6	58.2	37.9	22.0	34.7	10.0
		Longitudin	al at 350 F		
1L-7	52.0	38.0	24.0	62.7	9.6
1L-8	51.0	36.9	23.5	60 0	9,3
1L-9	52.0	38.0	25.0	60.0	9.
		Transvers	e at 350 F		
1T-7	53.0	26.0	20.0	44.0	8.9
1T-8	53.0	36.0	21.0	37.8	9.7
1T -9	53.5	35.6	22.0	44.0	8.7

TABLE XXV. (Continued)

Specimen	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Reduction in Area, percent	Tensile Modulus, 10 ⁶ psi
		Longitudin	al at 500 F		
1L-10 1L-11 1L-12	26.0 26.0 26.4	20.0 20.0 19.0	26.0 22.0 27.0	72.4 70.0 72.0	8.0 8.0 8.1
		Transvers	e at 500 F		
1T-10 1T-11 1T-12	27.0 26.4 27.0	19.0 18.7 17.6	20.4 20.0 24.0	65.0 68.0 60.0	7.6 8.2 8.0

TABLE XXVI. COMPRESSION TEST RESULTS FOR 2214-T351 PLATE

Specimen No.	0.2 Percent Offset Yield Strength, ksi	Compressive Modulus, 10 ⁶ psi
	Longitudinal at Room Temper	ature
2L-1	38.3	9.6
2L-2 2L-3	37.4 37.5	11.3 11.2
	Transverse at Room Tempera	ture
2T-1	44.2	11.2
2T-2 2T-3	44.9 4 4.8	10.3 10.0
	Longitudinal at 250 F	
2L-4	35.6	9.6
2L-5 2L-6	35.4 35.7	10.0 10.1
	Transverse at 250 F	
2T-4	40.0	10.1
2T-5 2T-6	40.6 39.2	10.1 9.8
	Longitudinal at 350 F	
2L-7	32.0	8.9
218 219	31.7 32.0	9.6 8.6
	Transverse at 350 F	
2T-7 2T-8	36.0 35.0	8.7 9.0
2T-9	35.0	8.6

TABLE XXVI. (Continued)

Specimen No.	0.2 Percent Offset Yield Strength, ksi	Compressive Modulus, 106 psi
	Longitudinal at 500 F	
2L-10	25.0	7.1
2L-11	24.2	7.1
2L-12	26.0	7.0
	Transverse at 500 F	
2T-10	25.6	7.1
2T-11	26.0	7.1
2T-12	24.9	7.1

TABLE XXVII. SHEAR TEST RESULTS FOR 2214-T351 PLATE

Specimen Number		Ultimate Shear Strength, ksi
	Longitudinal	
411		39.0
4L-2		38,8
4L-3		41.1
4L-4		41.2
	Transverse	
4T-1		38.7
4T-2		32.6
4T-3		38.6
4T-4		37.8

TABLE XXVIII. IMPACT TEST RESULTS FOR 2214-T351 PLATE

tala a satisfica a managalaga a la cul	
Specimen No.	Energy, ft-1b
<u>Longitud!nal</u>	
101-1	5.0
10L-2	6.0
10L-3	5.5
10L-4	4.0
Transverse	
10T-1	2,0
10T-2	1.5
10T-3	1.5
10T-4	2.5

TABLE XXIX. FRACTURE TOUGHNESS TEST RESULTS FOR 2214-T351 PLATE

Specimen Number	W, inches	a, inches	T, inches	P, 1bs	Span, inches	$f(\frac{a}{w})$	K _Q (a
			Transve	cse			
2T	1.500	.877	. 750	3,200	6	3.57	49.7
3 r	1.500	. 906	.750	3,600	b	3.8	60.1
4T	1.500	.866	.750	3,400	6	3,4	51.4
17	1.501	.845	. 750	2,950	6	3.29	42.3
			Longitud	<u>inal</u>			
6L	1,501	.880	.750	3,100	6	3,59	48.4
5L	1.501	.862	.751	3,100	6	3,4	46.2
7L	1,500	.819	.750	2,950	6	3.1	39.9
81.	1.500	,855	.750	3,100	6	3.38	45.6

⁽a) Candidate fracture toughness values, K_Q , are invalid as K_{1e} values since a, T, $+2.5~{\rm (K_Q)\over TYS)}$.

TABLE XXX. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED 2214-T351 PLATE (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5 -2	70 .0	(a)
5-4	60.0	12,210
5-3	55.0	39,870
5-1	50.0	67,850
5-23	47.5	147,100
5 -5	45.0	301,330
5 - 6	40.0	4,042,880
5-7	35.0	13,127,900 ^(b)
	250 F	
5-9	50.0	14,800
5-8	45.0	52 , 7 0 0
510	40.0	95,800
5-11	35.0	230,400
5-12	30.0	221 700
5~13	25.0	10,475,800 ^(b)
	350 F	
5-19	47.5	(a)
5-15	45.0	74,860
5-16	40.0	63,350
5 - 20	37.5	82,650
5-17	35.0	1/6 700
5-18	30.0	11,717,600 ^(b)

⁽a) Failed on loading.

⁽b) Did not fail.

TABLE XXXI. AXIAL-LOAD FATIGUE TEST RESULTS FOR NOTCHED ($K_{\rm t}$ = 3.0) 2214-T351 PLATE (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-1.	35.0	15,440
5-5	30.0	46,150
5-27	27.5	49,400
5-2	25.0	99,020
5-6	22.5	80,280
5-3	20.0	264,900
5 – 7	17.5	243,760
5-28	17.5	1,472,300 (a)
5-4	15.0	10,750,000 ^(a)
	250 F	
5-17	35.0	33,000
5-18	30.C	35,850
5-19	25.0	59,230
5-20	22.5	82,440
5-21	20.0	124,730
5-22	17.5	98,450
5 – 23	15.0	429,900
5-24	13.5	592,100
5-25	13.5	3,795,900 10,390,110 ^(a)
5-26	11,0	10,390,110 ^(a)
	350 F	
5-13	35.0	13,680
5-11	30.0	37,530
5 - 8	30.0	162,990
5 - 9	25.0	109,840
5-12	22.5	100,530
5-10	20.0	161,270
5-14	17.5	97,870
5-15	15.0	431,450 (a)
5-16	13.5	10,638,300

⁽a) Did not fail.

TABLE XXXII. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR 2214-T351 PLATE (TRANSVERSE)

Specimen	Striss,	Temp,	Hours	to 1	Indicated Greep Deformation, percent	p Deform	ation,	Initial	Rupture	Elongation	Reduction	Manimum Oreap
No.	No. Ksi F	ابنا	0.1	0.2	0.5	1.0	2.0	percent	hr hr	percent	or Area, percent	mate, percent/hr
 	50	250 250	250 0.2 250 10	0.7	2.7	6.4	450	0.592	20.7	11.1	43.0	0.14
36	35	250	07	145	;	1	í	0.459	264.3(a)			0.00.0
36	30	250	20	350	1670(5)	1	ł	0.315	550.7(a)		;	6.00321
3 2	57 #	350	0.8	2.4	6.5	Ø	ł	0.377	15.2	15.6	8. 	590"0
ተ ነ	1	350	22		125	200	270	0.263	337.8	18,5	77,1	0,0027
Ϋ́,	in M	350	145	390	1160(5)	4	e • •	0.104	432.8 ^(a)	0.333	ť	0.00342
رد م 1- م	(*• ¥	500	4.0	0.4	2.6	4.5	7.1	0.115	14.6	50.4	6) (1)	0.17
00000	ا الا ال	200	, ,	2. 55 5. 55	80 80	25 160	43 320	0.037	124.6 1192.4	40.0 26.6	73.1	6,037 6,0038
[:] m	1.5	500	9	425	2100(2)	i	;	0.070	748.8 ^(a)	0.322	;	0.00018

(a) Test discontinued.(b) Estimate.

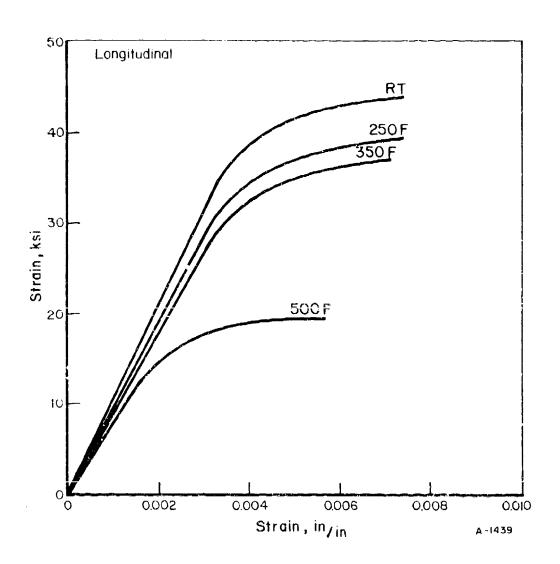


FIGURE 28. TYPICAL PENSILE STRESS-STRAIN CURVES FOR 2214-T351 PLATE (LONGITUDINAL)

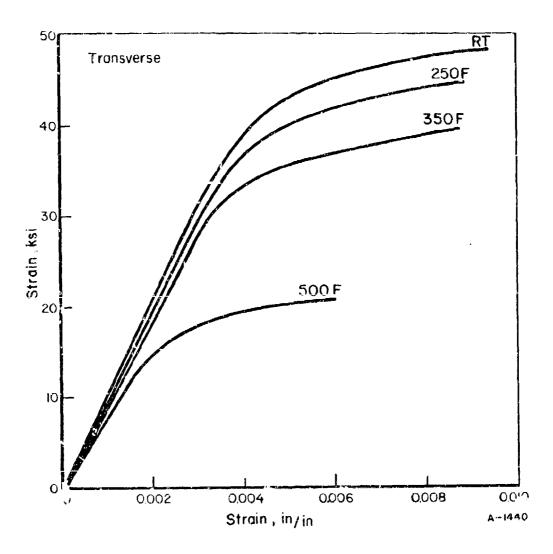


FIGURE 29. TYPICAL TENSILE STRESS-STRAIN CURVES FOR 2214-T351 PLATE (TRANSVERSE)

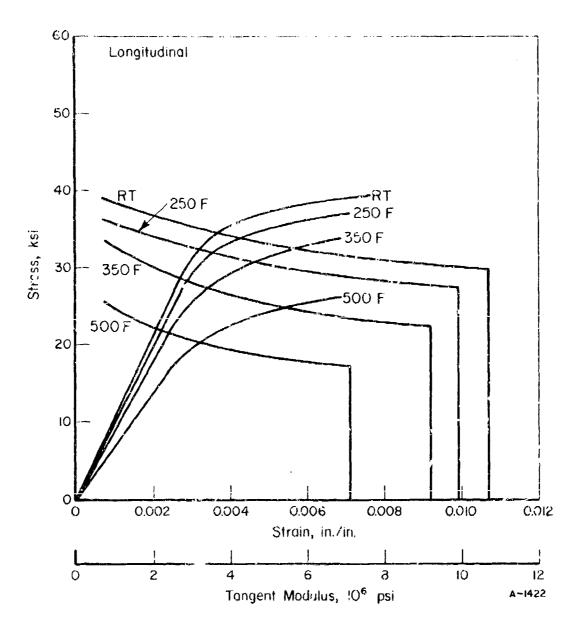


FIGURE 39. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR 2214-T351 PLATE (LONGITUDINAL)

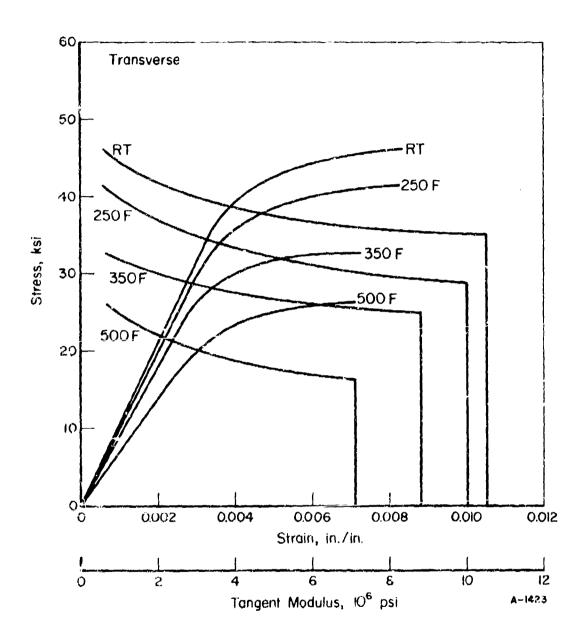


FIGURE 31. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENA MODULUS CURVES FOR 2214-T351 PLATE (TRANSVERSE)

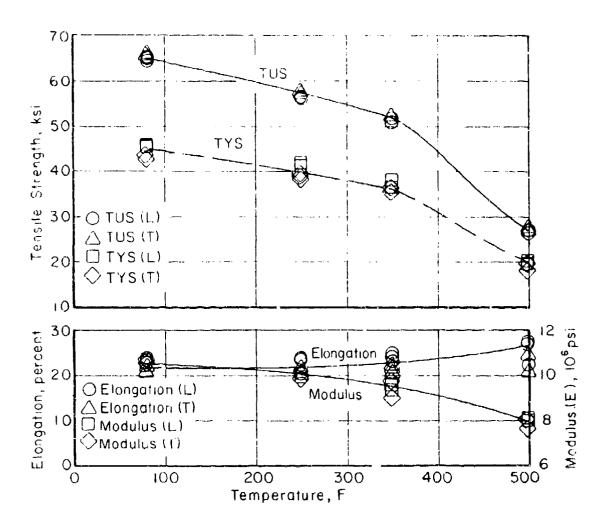


FIGURE 32. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 2214-T351 PLATE

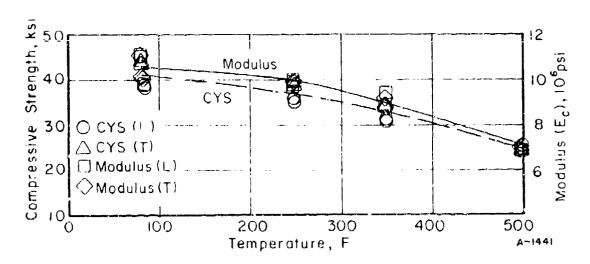


FIGURE 33. EFFECT OF TEMPERATURE OF THE COMPRESSIVE PROPERTIES OF 2214-1351 PLATE

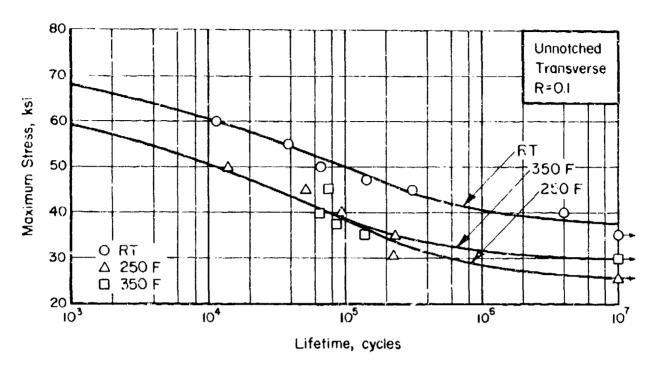


FIGURE 34. AXIAL-LOAD FATIGUE RESULTS FOR UNNOTCHED 2214-T351 PLATE

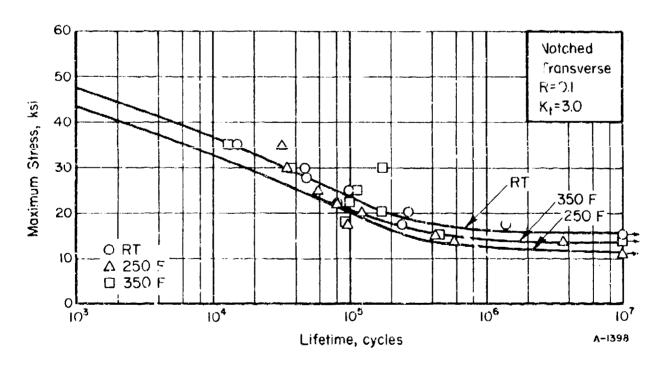
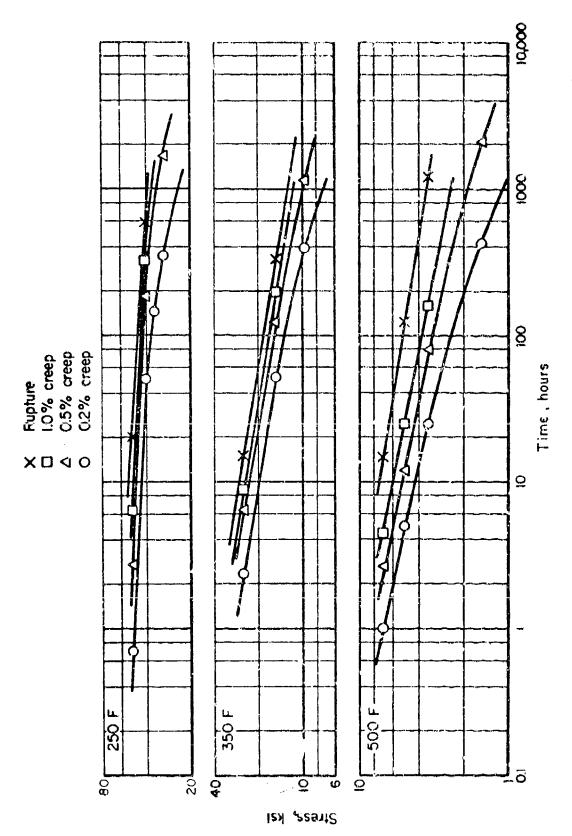


FIGURE 35. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED $(K_{L} = 3.0)$ 2214-T351 PLATE



STRESS-KUPTURE AND ELASTIC DEFORMATION CURVES FOR 2214-1351 FLAIE (TRANSVERSE) FIGURE 36.

Ti-bAl-4V Diffusion Bonded Component (DBHT)

Material Description

The material for this evaluation was supplied by the Air Force Materials Laboratory and consisted of pieces sectioned from a helicopter rotor hub. The rotor hub had been formed by diffusion bonding of 1/2-inch-thick Ti-6A1-4V plate. The evaluation material consisted of sections of the hub and lug ends.

Processing and Heat Treating

No specimen lay out is shown since the sections were quite complicated and it was necessary to out specimens from wherever the section thickness allowed. Where possible, the bond line of the plates was perpendicular to the specimen axis. No heat treating was done since material was received in diffusion bonded heat treated (DBHT) condition.

Test Results

Tension. Test results for transverse specimens at room temperature, 400 F, 700 F, and 900 F are given in Table XXXIII. Stress-strain curves are shown in Figure 37. Effect of temperature curves are presented in Figure 39.

Compression. Test results for transverse specimens are given in Table XXXIV for room temperature, 400 F, 700 F, and 900 F. Stress-strain and tangent modulus curves are presented in Figure 38. Effect-of-temperature curves are shown in Figure 40.

Shear. Pin shear test results for longitudinal and transverse specimens at room temperature are given in Table XXXV.

Impact. Impact test results are given in Table XXXVI for longitudinal and transverse specimens.

Fracture Toughness. The material was not of sufficient size or quantity for these tests.

Fatigue. Axial-load test results for transverse specimens at room temperature, 400 F, and 700 F are given in Tables XXXVII and XXXVIII. S-N curves are presented in Figures 41 and 42.

Creep and Stress Rupture. Test results for longitudinal specimens are presented in Table XXXIX. Log-stress versus log-time curves are presented in Figure 43 for 500 F, 700 F, and 900 F.

Stress Corrosion. Tests were conducted as described in the experimental procedures section of this report. No failures or cracks occurred in the 1000-hour test duration.

Thermal Expansion. The coefficient of expansion for Ti-6Al-4V is $5.7 \times 10^{-6} \frac{\text{Thermal Expansion}}{\text{in./in./F}}$ for 68 F to 900 F.

Density. The density of this alloy is 0.160 lb/in.3.

TABLE XXXIII. TENSILE TEST RESULTS FOR Ti-6A1-4V DIFFUSION BONDED COMPONENT (DBHT) (TRANSVERSE)

		aray separen		
Specimen No.	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Flongation in 2 Inches, percent	Tensile Modulus, 10 ⁶ psi
		Room Temperate	ure	
1T-1 1T-2 1T-3	153.0 151.0 150.0	143.0 142.0 145.0	11.5 10.0 12.0	15.8 16.0 16.0
		400 F		
1T-4 1T-5 1T-6	125.0 124.0 121.0	107.0 112.0 109.0	12.0 11.5 12.0	14.5 14.8 14.1
		700 F		
1T-7 1T-8 1T-9	106.0 107.0 108.0	90.2 87.4 88.5	8.5 9.5 8.5	13.0 12.6 12.0
		900 F		
1T-10 1T-11 1T-12	95.0 93.2 95.1	81.3 79.9 81.5	14.0 18.5 18.5	11.0 11.1 10.9

TABLE XXXIV. COMPRESSION TEST RESULTS FOR Ti-6A1-4V DIFFUSION BONDED COMPONENT (DBHT) (TRANSVERSE)

	er energia, en 1 general de la composition de la comp etition de la competition del	ABAMS SAMALIAN
	0.2 Percent	Compressive
Specimen	Offset Yield Strength,	Modulus,
No.	ksi	10 ⁶ psi
	Room Temperature	
2T-1	144.0	17.7
2T-2	147.0	18.1
2T-3	148.0	17.9
	400 F	
2T-4	111.0	16.7
2T-5	111.0	16.6
2T-6	112.0	16.5
	700 F	
2T-7	99.1	14.7
2T-8	95.6	16.0
2T-9	96.5	15.7
	900 F	
	900 F	
2T-10	96.4	14.7
2T-11	87.0	14.3
2T-12	85.0	14.6
	Contract to the second of the	A PRODUCTION OF THE PRODUCT OF THE PRODUCT OF THE PARTY.

TABLE XXXV. SHEAR TEST RESULTS FOR Ti-6A1-4V DIFFUSION BONDED COMPONENT (DBIT)

the submitted of the transfer of the
Ultimate
Shear Strength,
ksi
ongitudinal
91.0
92.7
93.7
ransverse
95.2
91.2
92.0

TABLE XXXVI. IMPACT TEST RESULTS FOR Ti-6A1-4V DBC (DBHT)

	ana is sialana are di dia a cia s	
Specimen No.		Energy, ft-1b
	l ngitudinal	
10L-1		11.0
10L-2		13.0
10L-3		17.0
10L-4		16.0
	Transverse	
10T-1		15.0
10T-2		16.0
10T-3		10.0
10T-4		12.0
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TABLE XXXVII. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED Ti-6A1-4V DBC (DBHT) (TRANSVERSE)

Specimen No.	Maximum Stress, ksi	Lifetime, cycles
	Rcom Temperature	
5-1	120.0	2,800
5-2	110.Ú	282,100
5-3	100.0	87,000
5-4	90.0	94,660
5-5	0,08	492,500
5-6	70.0	1,478,000
5-7	60.0	9,038,000
	400 F	
5-9	120.0	40
5~8	115.0	400
5-10	110.0	11,800
5-1.1	100.0	35,300
5-12	90.0	86,700
5~13	80.0	1,059,100
5-14	70.0	1,559,000
5-15	60.0	6,002,900
5–16	50.0	10,000,000
	700 F	
5-17	100.0	100
5-18	90.0	14,500
5-19	80.0	399,20 0
5-20	70.0	347,000
5-21	60.0	1,180,300
5-22	50.0	10,864,000

⁽a) Did not fail.

TABLE XXXVIII. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED ($K_C = 3.0$) Ti-6A1-4V DBC (DBHT) (TRANSVERSE)

Specimen No.	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-23	100.0	2,900
5-24	90.0	8,500
5-25	80.0	15,000
5-26	70.0	22,500
5-27	60.0	75,100
5-28	50.0	132,000 (a)
5-29	40.0	10,420,560 ^(a)
	<u>400 F</u>	
5-30	100.0	2,400
5-31	90.0	3,800
532	80.0	8,700
5-33	70.0	11,800
5-34	60.0	18,500
5-35	50.0	55,900
5-36	40.0	250,600 (a
5-37	30.0	12,609,000 (4
	<u>700 F</u>	
5-38	100.0	2,100
5-39	90.0	3,500
5-40	80.0	6,400
5-41	70. 0	8,900
3-42	60.0	12,500
5-43	50.0	76,200
5-44	40.0	860,700 (a
5-45	30.0	10,277,000

⁽a) Did not fail.

TABLE XXXIX, SUMMARY CREEP AND RUPTURE DATA FOR TI-6A1-4V DBC (DBHT) (LONGITUDINAL)

		Tempera-	H. O	Hours to Indicated Creep Deformation,	to Indicated Deformation,	cated		Initial	Rupture	Elongation	Minimum Creep
Specimen	Stress,	ture.		<u>т</u>	Percent			Strair,		in 2 Inches,	Rate,
Turk or		(Le	0.1	0.2	0.5	1.0	2.0	percent	મ	percent	percert/hr.
3		500	;	;	;		:		or loading		:
æ	, 4	500	:	;	;	;	!	:	on loading	×.5	;
. 1	110	500	0,05	0.40	4000	;	•	2.485	407.7%		0.00006
ć	() ()	Ü	Ċ	ć	est.	(1	176 6	36.7×	2,952	!
7	707	000	0,0	2	! !	ı	l !			1//:1	
· †	100	500	0.15	350	:	:	1	1.076	739.3*	1.286	ი. ეიეივ
(~	113	700	÷	;	!	;	!	;	on loading	2.5	:
, u	001	700	0.2	0.7	0.4	13	50	2.492	477.0		0.013
12	80	200	0' 7	20	155	069	1850	0.824	768.2*		0.00000
							est.	,			
15	65	200	50	115	1000	3500	i i	0.543	840.6*	1.014	0.00020
						est.					
-	95	006	i	{	;	;	:	;	0.1	11.9	;
7	08	006	i	0.01	0.05	0.15		1.353	2.3	19.1	5.1
α	09	006	0.07	0.2	8.0	2.5		0.676	8.09	35.7	0.27
11	20	006	0.15	7.0	2.7	7.0	20	0.402	194.6	45.5	0.085
ا	ι α. Σ	006	0.50	1.7	7.0	20	50	0.266	71.7	7.780	0.03
10	15	006	10	35	210	260	1900	0.033	863.1	, .953	6000.0

*Test discontinued.

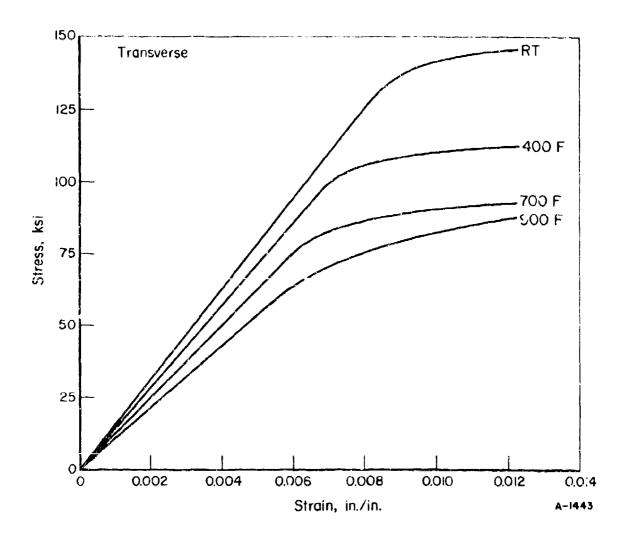


FIGURE 37. TYPICAL TENSILE STRESS-STRAIN CURVES FOR Ti-6A1-4V DBC (DBHT) (TRANSVERSE)

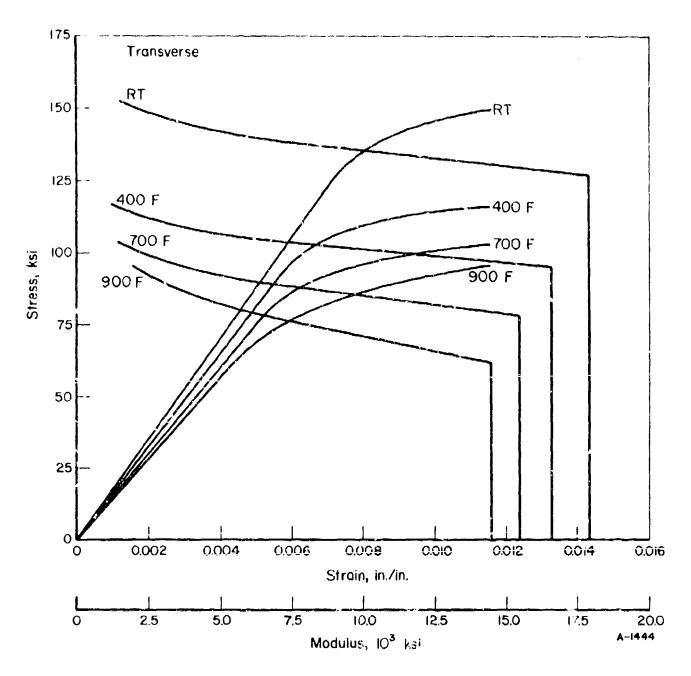


FIGURE 38. TYPICAL COMPRESSION STRESS-STRAIN AND TANGENT MODULUS CURVES FOR Ti-6A1-4V DEC (DBHT) (TRANSVERSE)

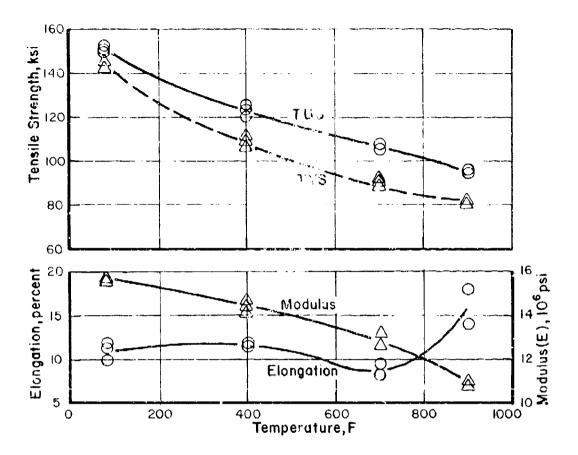


FIGURE 39. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6A1-4V DBC (DBHT)

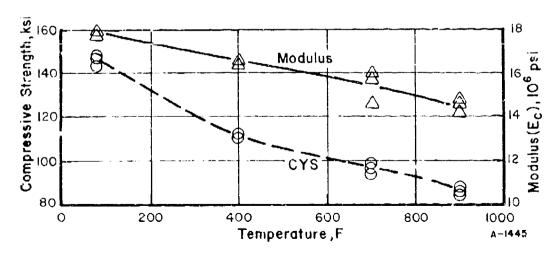


FIGURE 40. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF TI-6A1-4V DBC (DBHT)

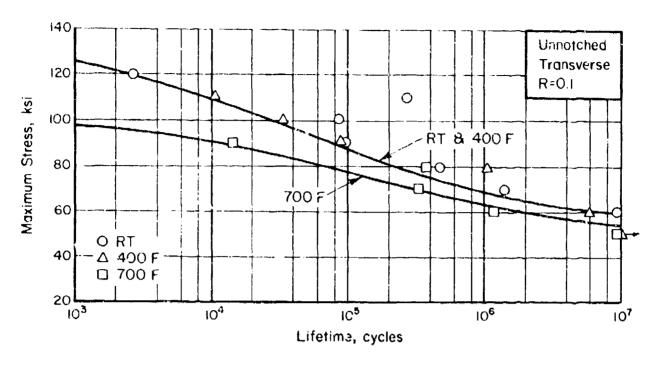


FIGURE 41. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED Ti-6A1-4V DBC (DBHT)

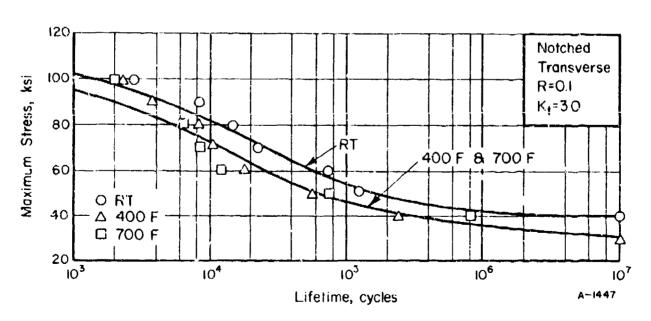
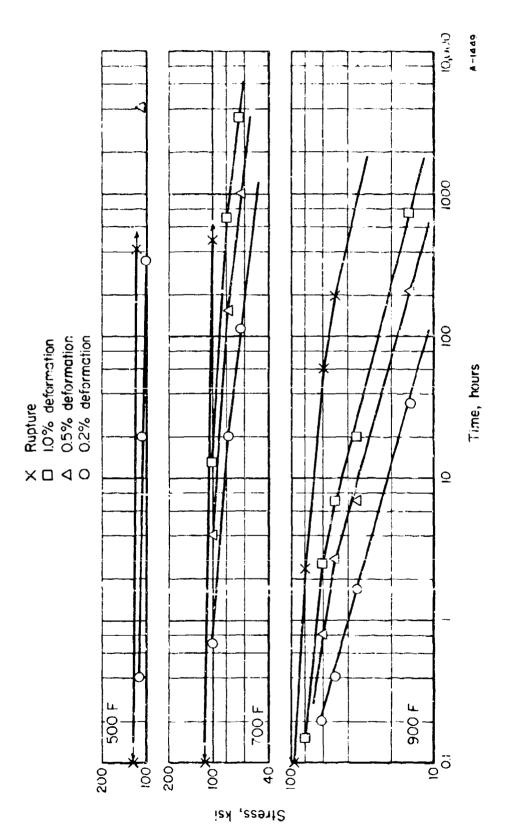


FIGURE 42. AXIAL-LOAD FATIGUE RESULTS FOR NOICHED $(K_t = 3.0)$ Ti-6A1-4V DBC (DBUT)



STRUSS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR T1-6A1-4V DBC (DBHT) (LONGITUDINAL) FIGURE 43.

DISCUSSION OF PROGRAM RESULES

The tendency in an evaluation program of this type is to compare the materials property information obtained with similar data on materials already in use. Whether such a comparison should be the deciding factor for interest in a newer alloy is open to question. Many criterial such as forming characteristics, weldability, oxidation resistance, etc., can be of particular importance so that strength properties may become secondary. However, since first comparisons are usually made on the basis of mechanical strength (tensile ultimate and tensile vield) the data generated on this program are compared to information for similar alloys. Figures 44 and 45 are effect of temperature curves concerned with these properties.

CONCLUSIONS

The objective of this program was the generation of useful engineering data for newly developed materials. During the contract term the following materials were evaluated:

- (1) 17-4 PH (H900) ESR Bar
- (2) Udimet 710 Forged Bar
- (3) X7050-T7E56 Hand Forging
- (4) 2214-T351 (Alcoa 417 Frocess) Plate
- (a) Ti-6A1-4V (a)BHT) Diffusion Bonded Component.

A data sheet was issued for each material. As a summary, each of the data sheets is reproduced in Appendix 111.

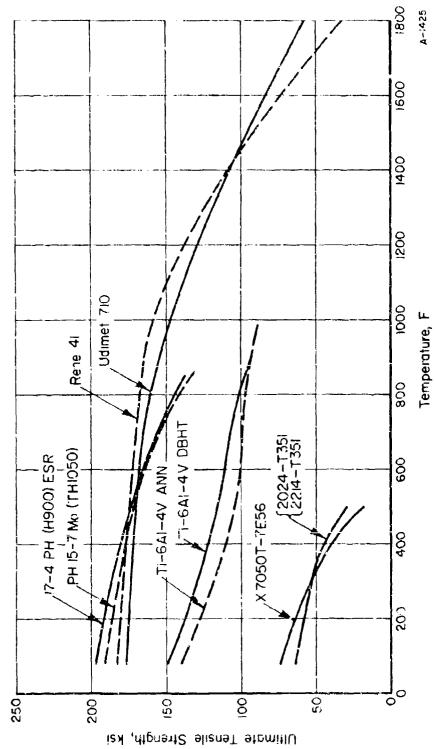


FIGURE 44. TENSILE ULIMATE STRENGTH AS A FUNCTION OF LEMPERATURE

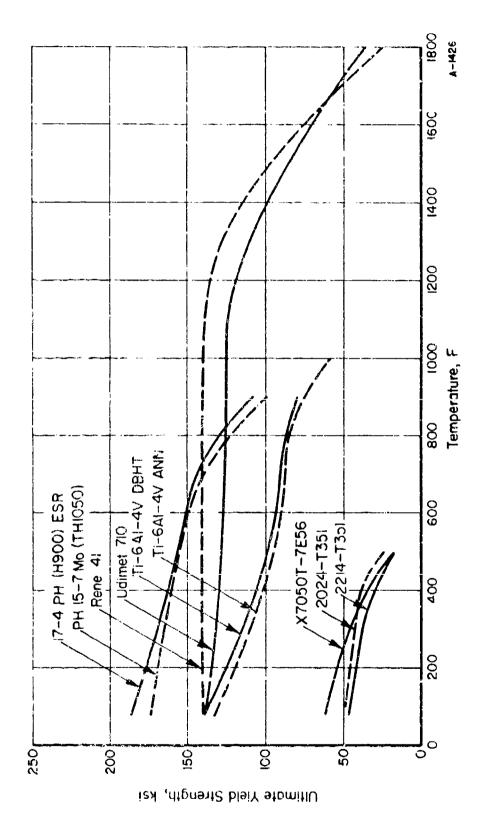


FIGURE 45. TENSILE YIELD STRENGTH AS A FUNCTION OF TEMPERATURE

APPENDIX I

EXPERIMENTAL PROCEDURE

APPENDIX T

EXPERIMENTAL PROCEDURE

Mechanical Properties

The various mechanical properties of interest for each of the materials are as follows:

- (1) Tension
 - (a) Tensile ultimate strength, TUS
 - (b) Tensile yield strength, TYS
 - (c) Elongation, e,
 - (d) Reduction in area, RA
 - (e) Modulus of elasticity, E.
- (2) Compression
 - (a) Compressive yield strength, CYS
 - (b) Modulus of elasticity, E.
- (3) Creep and stress-rupture
 - (a) Stress for 0.2 or 0.5 percent deformation in 100 hours and 1000 hours
 - (b) Stress for rupture in 100 hours and 1000 hours.
- (4) Shear
 - (a) Shear ultimate strength, SUS
- (5) Axial fatigue*
 - (a) Unnotched, R = 0.1, lifetime: 10³ through 10⁷ cycles

^{* &}quot;R" represents the algebraic ratio of the minimum stress to the maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. " K_t " represents the Neuber-Peterson theoretical stress concentration factor.

- (b) Notched ($K_t = 3.0$), R = 0.1, lifetime: 10^3 through 10^7 cycles.
- (6) Fracture toughness, K_{Ic} or K_{c}
- (7) Stress corrosion
 - (a) 80 percent TYS for 1000 hours maximum, 3-1/2 percent NaCl solution.
- (8) Thermal expansion.
- (9) Bend
 - (a) Minimum radius.
- (10) Impact
 - (a) Charpy V-notch.
- (11) Density.

Specimen Identification

A simple system of numbers and letters was used for specimen identification. Coding consisted of a number indicating the type of test and also indicating a comparable area on the sheet, plate, or forging. For certain test types, the number was followed by a letter signifying specimen orientation (L for longitudinal, T for transverse, ST for short transverse). The test types where the letter did not appear were creep, fatigue, and bend since, in these cases, only one specimen orientation was used. The next number in the coding specifies the location from which the specimen blank was taken from the original material configuration. Coding was as follows:

Assigned Number	Test Type
1	Tension
2	Compression
3	Creep and stress-rupture
4	Shear
5	Fatigue
6	Fracture toughness

Assigned Number	Test Type
. 7	Stress corrosion
8	Thermal expansion
9	Bend
10	Impact
11	Density

As an example, a specimen numbered 2-T5 is a compression specimen, transverse orientation, cut from Location 5. Also, a specimen numbered 5-12 is a fatigue specimen cut from Location 12.

Test Description

Tension

Procedures used for tension testing are those recommended in ASTM methods E8-68 and E21-66T as well as in Federal Test Method standard No. 151a (method 211.1). Six specimens (three longitudinal and three transverse) were tested at each temperature to determine ultimate tensile strength, 0.2 percent offset yield strength, elongation, and reduction in area. The modulus of elasticity was obtained from load-strain curves plotted by an autographic recorder during each test.

All tensile tests were carried out in Baldwin Universal testing machines. These machines are calibrated at frequent intervals in accordance with ASTM method E4-64 to assure loading accuracy within 0.2 percent. The machines are equipped with integral automatic strain pacers and autographic strain recorders.

Specimens tested at elevated temperatures were heated in standard wire-wound resistance-type furnaces. Each furnace was equipped with a Foxboro controller capable of maintaining the test temperature to within 5 F of the control temperature over a 2-inch gage length. Chromel-Alumel thermocouples attached to the specimen gage section were used to monitor temperatures. Each specimen was soaked at temperature at least 20 minutes before being tested.

An averaging-type linear differential transformer extensometer was used to measure strain. For elevated temperature testing, the extensometer was equipped with extensions to bring the transformer unit out of the furnace. The extensometer conformed to ASTM E3-64T Classification B1 having a sensitivity of 0.0001 inch/inch. The strain rate in the elastic region was maintained at 0.005 inch/inch/minute. After yielding occurred, the head speed was increased to 0.1 inch/inch/minute until fracture.

Compression

Procedures for conducting compression tests are outlined in ASTM Method E9-67 along with temperature control provisions of E21-66T. All sheet and thin plate tests were carried out in Baldwin Universal testing machines using a North American type compression fixture as shown in Reference 2. Specimen heating was accomplished by a forced-air furnace for temperatures up to 1000 F. Specimen temperature was maintained by means of a Wheelco pyrometer. Three Chromel-Alumel thermocouples attached to the fixture were used to monitor temperatures to within 3 F of the test temperature. For higher temperatures, wire-wound furnaces were used with controls as described in the tensile test section.

The extensometer used for the compression tests was quite similar to that used in the tensile testing. The extension arms were fastened to the specimen at small rotches spanning a 2-inch gage length. The output from the microformer was fed into a load-strain recorder to provide autographic load-strain curves. During testing the strain rate was adjusted to 0.005 inch/inch/minute.

For bar and forging material, cylindrical specimens similar to those described in ASTM E9-67 were used with appropriate temperature control and strain measurement as described above.

Six specimens (three longitudinal and three transverse) were tested at each temperature.

Shear

Single-shear sheet-type specimens were used for sheet and thin-plate material; for bar and forgings, a double-shear pin-type was used. Shear testing was performed at room temperature only. A minimum of six specimens (three longitudinal and three transverse) were used to determine ultimate shear strength.

Bend

The procedures for conducting bend tests are described in Report MAB-192-M. The specimens were placed in a rigid three-point loading fixture and bending tups of various sizes were used to determine the minimum bend radius at room temperature.

Creep an! Stress Rupture

Standard dead-weight type creep testing frames were used for the creep and stress-rupture tests. These machines are calibrated to operate well within the accuracy requirements of ASTM method E139-66T.

Specimens similar to those used for tension tests were used for the creep and stress-rupture studies. A platinum strip "slide rule" extensometer is attached for measuring creep strain and three Chromel-Alumel thermocouples are attached to the gage section for temperature measurements. Extensometer measurements were made visually through windows in the furnace by means of a filar micrometer microscope in which the smallest division equals 0.00005 inch.

The furnace was of conventional Chromel A wire-wound design with taps along the side to allow for correcting small temperature differences. Furnace temperature was maintained to within \pm 2 P by Foxboro controllers in response to signals from the centrally located thermocouple. The temperature of a specimen under test was stabilized for at least 1/2 hour prior to loading.

For each temperature condition creep and stress-rupture data were obtained to 100 and 1000 hours using as many specimens as necessary to obtain precise information. The percent creep deformation obtained was dependent on the material under test. In most instances stress-time curves were defined for 0.2 and 0.5 percent elongation.

Stress Corrosion

Seven specimens of each alloy were tested for susceptibility to stress-corrosion cracking by alternate immersion in 3-1/2 percent sodium chloride solution at room temperature.

Specimens were prepared for testing by degreasing with acetone. Where a surface tilm remained from heat treating, it was abraded off one side and the adjacent long edge of five of the specimens, and left intact on the other two.

Each specimen was placed in a four-point loading fixture and deflected to a stress corresponding to 80 percent of the tensile yield strength of the particular material. The specimen was electrically insulated from the fixture by means of glass or sapphire rods. Deflection for a given maximum fiber stress was calculated by the following expression:

$$y = \frac{\sigma(3L^2 - 4a^2)}{12dE}$$

whe re

y = deflection

 σ = maximum fiber stress

t = distance between outer !oad points

a = distance between outer and inner load points

d = specimen thickness

E = modulus of specimen material.

Each stressed specimen was suspended on an alternate immersion unit. This unit alternately immersed specimens in the 3.5 percent sodium chloride solution for ten minutes and held them above the solution to dry for 50 minutes. Tests were continued to the first sign of cracking or for 1000 hours, whichever occurred first.

Specimens were given frequent low-power microscopic examinations to detect cracks. At the first sign of cracking the specimen was removed. At the conclusion of the test, selected samples were sectioned and examined metallographically for any indication of cracking. Representative samples in which cracks were found were also given a metallographic examination to establish the type and extent of the cracks.

Thermal Expansion

Linear-thermal-expansion measurements were performed in a recording dilatometer with specimens protected by a vacuum of about 2×10^{-6} mm of mercury. In this apparatus a sheet-type specimen is supported between two graphite structures inside a tantalum-tube heater element. On heating, the differential movement of the two structures caused by specimen expansion results in the displacement of the core of a linear-variable differential transformer. The output of the transformer is recorded continuously as a function of specimen temperature. The entire assembly is enclosed in a vacuum chamber.

The furnace is controlled to heat at the desired rate, usually 5 F per minute. Errors associated with measurements in this apparatus are estimated not to exceed \pm 2 percent. This is based on calibration with materials of known thermal-expansion characteristics.

Fatigue

Fatigue tests were conducted using MTS electrohydraulic-servocontrolled testing machines. The frequency of cycling of these machines is variable to beyond 2,000 cpm depending on specimen rigidity. These machines operate with closed-loop deflection, strain or load control. Under load control used in this program, cyclic loads were automatically maintained (regardless of the required amount of ram travel) by means of load-cell feedback signals. The calibration and alignment of each machine are checked periodically. In each case, the dynamic load-control accuracy is better than + 3 percent of the test load.

For elevated temperature studies, an induction heating coil controlled by a Lepel Induction Heater was used. A thermocouple placed on the center of the specimen controlled temperature to + 5 degrees.

After machining and heat treating (when required), the edges of all sincer and plate specimens were polished according to Battelle-Columbus' standard practice prior to testing. The unnotched specimens were held against a rotating drum covered with emery paper and polished using a kerosene lubricant. Successively liner grits of emery paper were used, as required, to produce a surface

of about 10 RMS. Unnotched round specimens were polished in the Battelle-Columbus polishing apparatus. This machine utilizes a rotating belt sander driven rectilinearly along the specimen test section while the specimen is being rotated. The belt speed and specimen speed are adjusted so that polishing marks on the specimen are in the longitudinal direction. The surface finish is about the same as that on the flat specimens. The notched flat specimens were held in a fixture and polished with a slurry of oil and alundum grit applied liberally to a rotating wire. Notched round specimens are polished in the same manner, except that the specimen is rotated.

A shadowgraph optical comparator was used for measuring the test sections of all polished specimens and for inspection of the root radius in the case of the notched specimens.

The stress ratio for all specimens was R = 0.1. Stresses for notched (K_t = 3.0) and unnotched specimens were selected so that S-N curves were defined between 10^3 and 10^7 cycles using approximately 10 specimens for each set of fatigue conditions.

Fracture Toughness

Two types of fracture toughness tests were used. For heavy section materials, the chevron-notched, slow bend test specimen of ASTM Method E-399-72 was selected. For thinner section sheet materials, center through-cracked tension panels were used as test specimens. All specimens were precracked in fatigue and subsequently fractured in a servocontrolled electrohydraulic testing system of appropriate load capacity.

The slow-bend type specimens were precracked and tested under 3-point loading. The pop-in load for materials susceptible to brittle fracture was determined from the load-compliance curve. When pop-in was not detectable, the curves were analyzed using the 5 percent secant offset method of the ASTM procedure.

The thin sheet center through-crack tension panels were initially sawcut and then precracked in constant amplitude fatigue loading. In order to maintain a flat fatigue crack and not plastically strain the uncracked section, the maximum stresses were adjusted to keep the applied stress-intensity factor less than one-third or one-quarter of that anticipated at fracture. This usually involved stepping down the stresses as the cracking proceeded. The crack was extended to approximately one-quarter of the panel width. Buckling guides were attached and a clip-type compliance gage was mounted in the central notch. The panels were fractured in a rising load test at a stress rate in the range

.002 E $< \dot{S} < .005$ E ksi/min

which corresponds nominally to the gross strain rate of standard tensile testing.

APPENDIX 11
SPECIMEN DRAWINGS

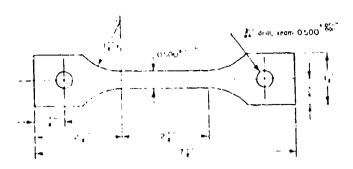


FIGURE 46. SHEET AND THIN-PLATE TENSILE SPECIMEN

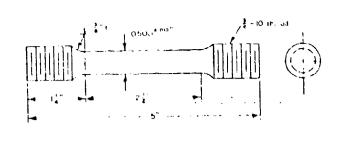
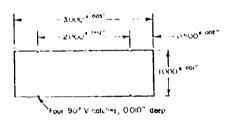


FIGURE 47. ROUND TENSILE SPECIMEN



Notes 1 Ends must be flat and parallel to within 0.0002"

2 Surface must be free from micks and scrutches

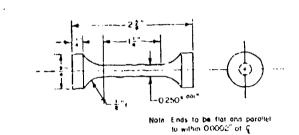


FIGURE 49. ROUND COMPRESSION SPECIMEN

FIGURE 48. SHEET COMPRESSION SPECIMEN

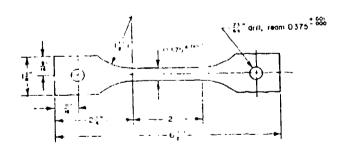


FIGURE 50. SHEET CREEP - AND STRESS... RUPTURE SPECIMEN

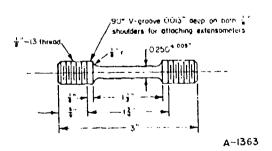


FIGURE 51. ROUMD CREEP - AND STRESS-RUPTURE SPECIMEN

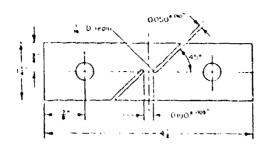


FIGURE 52. SHEET SHEAR TEST SPECIMEN



FIGURE 53. PIN SHEAK SPECIMEN

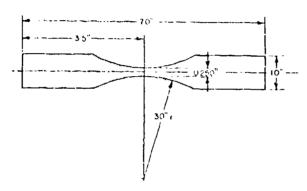


FIGURE 54. UNNOTCHED SHEET FATIGUE SPECIMEN

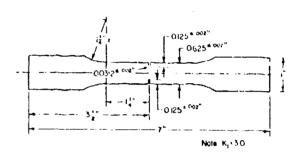


FIGURE 55 . NOTCHED SHEET FATIGUE SPECIMEN

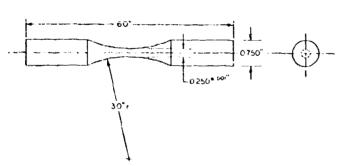


FIGURE 56. UNNOTCHED ROUND FATIGUE SPECIMEN

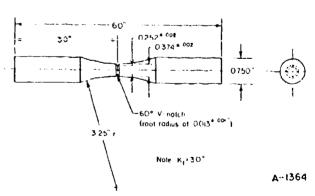


FIGURE 57. WOTCHED ROUND FATIGUE SPECIMEN

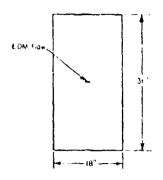


FIGURE 58. SHEET FRACTURE TOUGH-NESS SPECIMEN

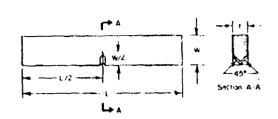


FIGURE 59. SLOW BEND FRACTURE TOUGHNESS SPECIMEN

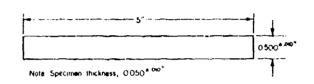


FIGURE 60. STRESS-CORRUSION SPECIMEN

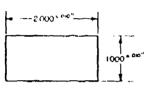


FIGURE 61. THERMAL-EXPANSION SPECIMEN



FIGURE 62. SHEET BEND SPECIMEN

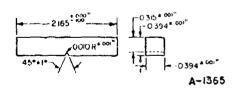


FIGURE 63. NOTCHED IMPACT SPECIMEN

APPENDIX 111

DATA SHEETS

17-4 Pil (1990) Bar (ESR)

Macutal fuscription

Ints alloy is the family of precipitation hardening stainless steels thich have found wide usage in aerospace, industrial, and commercial applications. The particular material used in this evaluation was produced by the Electrosiag Renelting (ESR) process. In this process an electrode (in this contained in an open-bottomed water-cooled metal mode. The melted metal forms a pool beneath the flux bath and progressively solidifies forming an ingel which is continuously extracted from the mold.

The metal is refined and desulfurized by flux action and the microstructure is improved by cont. The solidification.

The material used in this evaluation was a 3.3-inch-diameter bar from Heat 02295. Chemistry was as follows:

	Percent.	20.0	0.73	0.41	0.15	0.03	15.9	4.45	3.45	0.23	Balance
Chemical	Composition	Cathon	Aanganese	Stitcer	Pt.osphorus	Sulfur	Chromium	Nickel	Copper	Columbium	Tron

Processing and Reat Treating

Specimens were tachined in the astrectived Condition A followed by hest treatment at 900 F for I hour to Condition H 900.

17-4 PH ESR Data (5)

Condition: M950 Product: 3.3-inch dismeter bar

Tris 1972 1775 1674 1977			Temperature	ure, F	
ngitudinai), kei ngitudinai), kei ngitudinai), kei ngitudinai), kei itudinai), percent itudinai), percent itudinai), lo^ pei ngitudinai), kei ngitudinai), kei ngitudinai), kei ngitudinai), kei ngitudinai), kei ngitudinai), kei ngitudinai), kei ngitudinai) ng	Properties	RT	697		003
### 197.2 177.5 166.4 ### 197.2 177.5 166.4 ### 185.6 159.3 145.0 ### 185.6 159.3 145.0 ### 185.6 159.3 145.0 ### 185.6 159.3 145.0 ### 185.6 159.3 145.0 ### 185.6 159.3 145.0 ### 185.6 159.3 145.0 ### 185.6 139.5 ### 185.6 139.5 ### 185.6 139.5 ### 185.6 139.5 ### 185.6 ### 185.6 ### 185.6 ### 185.6 ### 185.6 ### 185.6 ### 185.6 ### 185.6 ### 185.6 ### 185.6 ### 185.6 ### 185.6 ### 185.6 #### 185.6 #### 185.6 #### 185.6 #### 185.6 ####################################	Tension				
### 175.0 155.6 159.3 145.0 ### 175.1 10.9 5.9 ### 175.1 10.9 ### 175.1 10.9 ### 175.1 10.9 ### 175.2 137.6 147.9 ### 175.1 147.9 139.5 ### 175.1 147.9 139.5 ### 175.1 147.9 139.5 ### 175.1 147.9 139.5 ### 175.1 147.9 139.5 ### 175.1 147.9 139.5 ### 175.1 147.9 139.5 ### 175.1 147.9 139.5 ### 175.1 ### 175.1 139.5 ### 175.1 139.5 ### 175.1 139.5 ###	TUS (longicudinal), k#1	197.2	177.5	160.4	133.4
Second S		165.6	159.3	145.0	108.2
gltudinal), percent 48.3 37.6 34.9 fludinal), 10° psi 28.7 26.5 24.0 on gltudinal), ksi 173.1 147.9 119.5 gltudinal), ksi 173.1 147.9 119.5 gltudinal), ksi 173.1 147.9 119.5 gltudinal), ksi 173.1 147.9 119.5 charpy, ft. 1b. 22.2 0 U sverse) charpy, ft. 1b. 25.5 24.0 0 sverse) charpy, ft. 1b. 25.5 24.0 0 sverse) charpy, ft. 1b. 25.5 24.0 0 sverse) charpy, ft. 1b. 25.5 24.0 0 sverse) charpy, ft. 25.5 24.0 0 sverse) charpy, ft. 25.5 24.0 0 sverse) charpy, ft. 25.5 24.0 0 sverse) charpy, ft. 25.5 24.0 0 sverse) charpy, ft. 25.5 24.0 0 sverse) charpy, ft. 25.5 24.0 0 sverse) charpy, ft. 25.5 24.0 0 sverse) charpy, ft. 25.5 24.0 0 sverse) charpy,	fn 2	17.1	10.9	٠ د	9.7
Section 10° pet 28.7 26.5 24.0	RA (longitudinal), percent		37.6	34.9	34.46
On 173.1 147.9 119.5 gltudinal), kal 117.3 147.9 119.5 gltudinal) 117.3 U(c) U Charpy, ft. 1b. 22.2 D U secree) 21.7 U U Toughness 48.2(e) U U ngitudinal) 48.2(e) U U secree) U U U secree) U U U sycles, kal 1139 118 ycles, kal 103 99 74 ycles, kal 103 90 76 ycles, kal 136 90 76 ycles, kal 39 50 42 ycles, kal 39 50 42 ycles, kal 30 50 42	E (longitudinal), 10° psi		26.5	24.0	22.3
### 173.1 147.9 119.5 ###################################	Compression				
### Structural of the control of the		173.1	147.9	139.5	117.6
Charpy, ft. 1b. Charpy, ft. 1b. Loughness severae) Studinal), kel An. Loughness Loughness Ague (longitudinal)(f) Loughness		30.2	26.9	24.7	23.9
Charpy, ft. 1b. Charpy, ft. 1b. Studinal) Studinal St	Shear (b)				
Gltudinal), Kai		•	(5)"		;
Charpy, ft. 1b. tudinal) verse) verse) 22	SUS (longitudinal), kal	61/17	3.	د	د
22 2 0 U 21.7 U U 48.2(e) U U 120 139 118 121 109 99 103 90 76 136 90 76 39 50 46 30 50 42	I. PACE (d)				
22 2 0 U 21.7 U U 48.2(e) U U 170 139 119 121 109 99 103 90 76 39 50 46 30 50 42	نے				
110 139 118 121 109 99 103 90 76 136 90 76 136 90 76 136 90 76 130 50 42		22 2	Þ;	- :	5 :
48.2 ^(e) U U 170 139 118 121 109 99 103 90 74 136 90 76 39 50 48 30 50 42	(riphacerse)	71.7	•	ɔ	ə
18.2(e) U U 170 139 119 121 109 99 103 90 76 136 90 76 39 50 48	Fracture Toughness				
170 139 118 121 109 99 103 90 74 136 90 76 39 53 48 30 50 42		48.2(e)	3	. =	5
170 139 119 121 109 99 . 103 90 74 136 90 76 39 53 48	, T				
kei 170 139 119 188 188 189 99 kei 103 90 74 188 188 189 188 188 189 189 kei 103 90 76 188 188 188 188 189 189 189 189 189 189	Axial Fatigue (longitudinal)'1'				
kai 170 139 118 18 18 18 18 18 18 18 18 18 18 18 18					
kei 109 39 74 75 103 90 74 75 103 103 90 76 104 105 105 105 105 105 105 105 105 105 105		170	139	113 20	p :
3.0, R = 0.1 136 90 76 kst 136 90 76 kst 39 53 48 kst 30 50 42	cycles.	103	66	74) F3
kai 136 90 76 kai 39 53 48 kai 30 50 42					
kat 39 53 48 kat 30 50 42	k 81	136	8	16	Þ
cycles, ksi 30 50 42		39	53	848	כ
	cycles,	90	50	77	>

17-4 PH ESR Data (continued)

		Temperature, F	ure, F	
Properties	RT	700	606	1100
Creep (longitudinal)				
0.2% plastic deformation, 190 hr, kei	NA	140	35	12
0.2% plastic deformation, 1000 hr, kei	ΚΆ	130	18	7
Stress-Rupture (longitudinal)				
Rupture, 100 hr. ksi	N.A.	ε	85	30
Rupture, 1000 hr, kai	¥	(F)	53	16
Stress Correston (B)				
80ੀ TVS, 1000 hr maximum	no cracks			

6.5 x 10 6 1n./fr /F (68 to 900 F)

nstty

0.233 15/50.3

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; everage of 4 tests.

U, unavailable; NA, not applicable.

() (3)

Average of 5 tests.

 (a) Insect longitudinal slow-bend apectmens were tested. Specimen size was 0.750inch thick by 1.530 inches wide with a span of 6 inches. (f) "R" represents the algebra's ratio of minimum stress to maximum etress in one cycle; that is, R=5 fS . "Y" represents the Neuber-Peterson theoretical stress concentration Takiomax

(g) Room-temperature three-print bend test. Alternate immersion in 3 1/22 NaCl.

(h) Not determinable from test results.

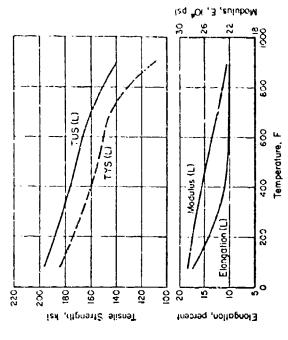
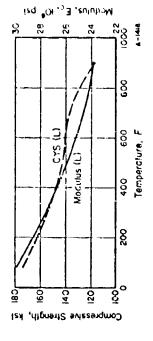
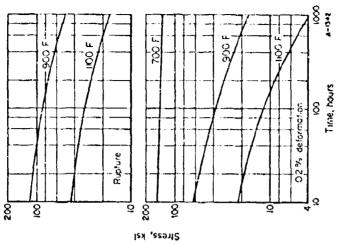


FIGURE 1. EFFECT OF TEMPERATURE ON THE TEMSILE PROPERTIES OF 17-4 PH (H900) BAP (ESP)



PICURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 17-4 PH (H900) AAR (EGA)



Tine, hours 4-1342
FIGURE 5. STRESS-RUPTURE AND PLASTIC DEPORMATION
CURVES FOR 17-4 PH (H930) BAR (ESR)

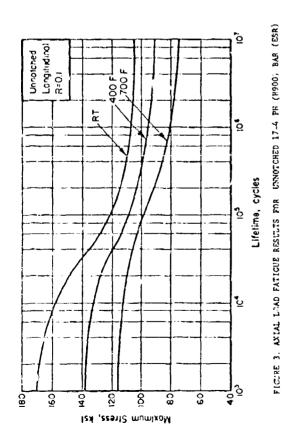


FIGURE 4, AXIAL LOAD PATIGUE RESULTS FOR NOTCHED (Kt-3.0) 17-4 PH (H900) BAR (ESR)

Udimet 710 Forged Bar

Material Description

Udinct 71% was recently developed by Special Metals Corporation to fill the need for a jet engine turbine bloding allow, combrings the high etrongth and stubility tharmer.ctssics of fulture 170 winn the correston and walfidation resistance of 15% chronium alloys such as the older Udinet 500 and Waspaioy. The allow is designed for use in either the wrought or cast form. Data generated at Special Netais from laboratory heats show it to have rupture strengths superior to Udinet 700, good oxidation and hot correction resistance and excellent phase stability after extended exposure to attess on the temperature. Data are now being generated from production scale heats for both cast and wrought forms.

The natorial used for this evaluation was Special Metal Corporation heat No. 8-2814. The alloy was obtained as 1.875 inch diameter bar with the following composition:

Percent	0.07	0.10	0.10	18.0	14.8	0.14	3.10	1.47	4. 88	2,51	0.018	0.04	0.003	Balance
Chemical Composition	Garbon	Manganese	Silicon	Chromium	Cobalt	Iron	Rolybdenum	Tungsten	Ittanit	Aluathum	Boron	unjuozij2	Sulferz	Mickel

Processing and Heat Treating

Hest treatment, as suggested by Special Metals, was as follows:

- (1) 2150 F for 4 hours, air cool,
- (2) 1975 F for 4 hours, air cool,
- (3) 1550 F for 24 hours, air cool,
- (4) 1450 F for 16 hours, air conl.

UDIWET 710 Alloy Data (a)

Condition: Solution Treated and Aged Product: 1.875-inch forged bar

		4	ь	
Properties	R.	8:00	J~ 1	1800
Tension				
TUS (longitudinal), kai	177.7	165.1	183.9	55.0
TYS (longitudinal), kat	138.0	122.8	122.9	37.0
e (longitudinal), percent in 2 in.	7.2	7.6	15.3	30.0
RA (longitudinal), percent	6.7	9.5	14.6	55.3
E (lorgitudinal), 10° pai	28.5	24.2	50.5	18.8
Compression				
CYS (lone(tudinal), kai	149.7	127.0	118.5	37.3
	30.6	25.5	22.5	18.2
Shear (b)				
SUS (longitudins:), ksi	126.3	(c)	ដ	5
Impact (d)				
V-notch Charpy, ft, 1b. (longitudinal)	17.3	a	ټ	ວ
Fracture Toughness				
Kic (longitudinal), kai /in.	•	သ	į,	ນ
Axial Fatigue (transverse)(f)				
Unnotched, R = 0.1				
10° cycles, ksi	160	171	12:	:1
106 cycles, ksi	125	93	5.5	:>
	100	20	76	i:
ć, X	e e	í	ŗ	:
cycles,	£3,	3 :		> :
cycles,	99	7	7	: ر:
10' cycles, ksi	27	27	07	ບ

UDINET 710 Alloy Data (continued)

	İ		ature, F	
Properties	RT		1909 1400	1961
(3525AS/E11) Chau				
6.2% plastic deformanter, 100 hr, kei	N.A	110	ó£	7
0.2% plastic deformation, 1000 hr. ksl	NA	121	36	♥
Strees Repture (long transverse)				
Rupture, 100 hr., ksf.	ž	167	\$5	60
Ruplure, 1000 hr, kai	Ŗ	160		64
Strens Corrosion (5)				
SOT TVS, 1000 hr maximum	no cracks			

Sovificians of Incomal Expansion 8.7 x 10⁻⁴ in./in./F (70 to 1400 F)

A 4 6 5 C

6.292 lb/fn.3

(a) Values are average of trivileare tests conducted at lattelle under the subject contract unless otherwise indicated. Fatigme, creep and stress-rupture values are from curves generated using the results of a greater number of sests.

(b) Double-shear plantyme specimen; average of 4 tests.

U, unavailable; NA, not applicable,

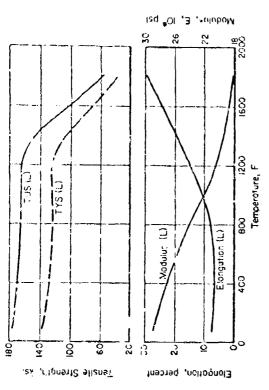
§ §

Average of 6 tests.

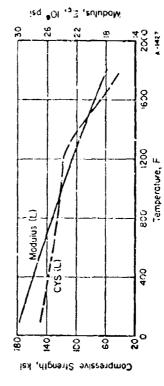
(e) Four longitudin i slow-bend speckmens were tested. Speckmen state was 0.750-inch thick by 1.50C inches wide with a span of 6 inches. The overage Kg obtained was 79.4 ksivin. Since the size ratio, 2.5 (Kg/TYS)?, was greater than both the speciment intekness and crack length in all resta, this Kg value is not a valid Kg value by existing ASTM criteria.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that [s, R * S_in/S_ax* "K," represents the Neuber-Peterson theoretical stress concentration factor.

(4) Acom-temperature three-point beni test. Alternate immersion in 3 1/2% NaCl.



PIGURE 1, EFFECT OF TEMPERATURE OF THE TENSILE PROPERTIES OF UDENET 710 FORGED BAR



PICURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF UDINET 710 FORCED BAR

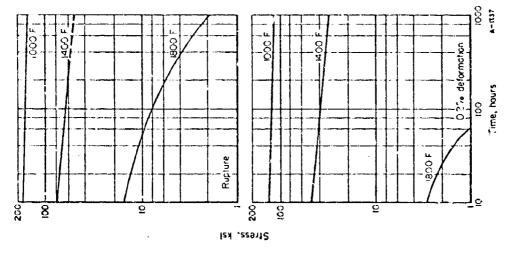
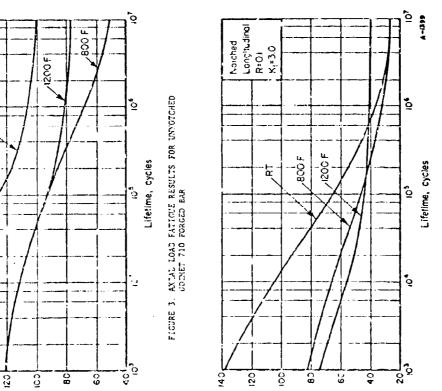


FIGURE 5. STRESS-RUFTURE AND FLASTIC DEFORMATION CLEVES FOR UDINET 710 FORGED BAR



Longitudinal R = 0.

7

0

Meximum Stress, ksi

3

Unnotehe 1

FIGURE 4. AXIAL 19AD FATIGUE RESULIS FOR NOTCHED $(\kappa_{\rm p}^{-} 3.0)$ udimet 7.2 forced bar

led , eessy? mumixoM

7050-77555 Hand Forging

Material Description

Alloy 70%0 is an Al-Zn-kg-Cu alloy developed by the Alcoa Research Laboratories supported by the Naval Air Systems Compand and the Air Force Materials Laboratory. When heat treated and aged to the -173 temper, thick 7050 place and hand forgings exhibit strengths equal to or exceeding those of 7079-16XX products combined with improved fracture toughness and a high resistance to exfoliariation and stress-corresion cracking. The alloy differs from conventional 7XXX series aluminum alloy, in that zirconium is added and chromium and manganese are restricted in order to minimize quench sensitivity.

The material used for this evaluation was a 5-inch by 10-inch by 5-foot hand forging produced within the rollowing composition limits:

Percent	2.0 to 2.8	0.15 max	0.12 max	C. 10 max	1.9 to 2.6	5.7 to 6.7	6.04 max	C.06 Bax	Balance
Chemical Composition	Copper	Iron	Silicon	Manganese	Magnesium	Zinc	Chrosius	Titanium	Al·minom

Processing and Heat Treating

The specimens were tested in the as-received -17256 temper.

7000-17556 Muminum, Alloy Data (a)

Thickness: 5-fach x 10-inch hand forging

Tune Properties	mgtudinal), ksf ansverse), ksf ori transverse), ksf ori transverse), ksf intednal), percent in 2 in. isverse), percent in 2 in. isverse), percent in 2 in. gitudinal), percent insverse), percent insverse), percent insverse), percent insverse), percent insverse), percent insverse), lof psi isverse), ksf ansverse), ksf insverse), ksf			000 18.6 19.4 1.61 1.61 1.62 1.62 1.63 1
### ##################################	rgttudinal), ksf ansverse), ksf ort transverse), ksf rgitudinal), ksi ort transverse), ksf itudinal), percent in 2 in. it transverse), percent in 2 in. it transverse), percent in 2 in. it transverse), percent insverse), percent itudinal), jore it transverse), percent itudinal), iof psi re transverse), lof psi gleddinal), isf ansverse), lof psi insverse), lof psi insverse), ksi ansverse), ksi charpy, fr. 1b.		•	8.1.1.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
refrudinal), ksi ansverse), ksi ansverse), ksi ansverses), ksi ansverses), ksi ansverses), ksi ansverses), ksi ansverses), ksi ansverses), ksi ansverses), ksi ansverses), percent in 2 in. situdinal), percent in 2 in. situdinal), ksi ansverses), lof psi ansverses), lof psi ansverses), lof psi ansverses), ksi ansverses	engitudinal), ksi ansverse), ksi ori transverse), ksi anoverse), ksi anoverse), ksi itudinal), ksi siverse), percent in 2 in. siverse), percent in 2 in. gitudinal), percent in transverse), percent in transverse), percent in transverse), percent in transverse), percent in transverse), io psi isverse), io psi isverse), io psi insverse), ksi anosverse), ksi insverse), k	·	•	18. 25. 27. 27. 27. 27. 27. 27. 27. 27. 27. 27
ansverse), ksi ort transverse), percent in 2 in. situdinal), percent ort transverse), percent ort transverse), percent ort transverse), percent ort transverse), percent ort transverse), percent ort transverse), percent ort transverse), percent ort transverse), percent ort transverse), percent ort transverse), percent ort transverse), percent ort transverse), log psi ansverse), log psi ort transverse), log psi ort tr	ansverse), ksi ansverse), ksi ansverse), ksi ansverse), ksi ansverse), ksi incurational), ksi incurational), percent in 2 in. istedinal), percent it transverse), percent it transverse), percent it transverse), percent it transverse), percent it transverse), percent it transverse), lof psi isverse), lof psi ansverse), ksi ansverse), ksi ansverse), ksi ansverse), ksi ingttudinal), ksi ansverse), ksi charpy, fr. 1b.		•	2,000 D
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### ##################################	ngttudinal), ksi naverse), lof psi ngttudinal), ksi ansverse), ksi charpy, ft. 1b.			21.5
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07 cycles, ksi 30 22 18	cycles, kei	30	24	:2
	O' cycles, kai	22	89	در:

7050-I?E56 Aluminum Alloy Data (continued)

		Tensera	Temperature, F	
Properties	EZ	256	350	\$00
Axial Fatigue (transverse) (continued)				
Notched, K. m 3.0, R m 0.1	Ş	Ş	۲,7	Þ
10° cycles, ksi	27	2 2	7	:
10 cycles, ksi	12	12	12	Þ
Creep (transverse)				
0.22 plastic defermation, 100 hr, kei	NA.	0,7	16	3,5
0.2% plastic deformation, 1000 hr, ksi	K'A	35	11	2.1
Stress Rubture (transverse)				
Rupture, 100 hr, ksi	Ϋ́Α	45	77	9
Rupture, 1000 hr, ksi	2	38	14	4
Stress Corresion (8)				
80% TYS, 1000 hr maximum	no cracks			

12.8 x 10" in./in./F (68 to 212 F)

Density

0.102 1b/in.3

- (a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, treep, and stress-rapture values are from curves generated using the results of a greater number of tests.
- (b) Double-shear pin-type specimen; average of 4 tests.
- U, unavailable; NA, not applicable.

9

- (d) Average of 6 tests.
- (e) Four longitudinal glow-bend specimens were tested. Specimen size was 0.750-inch thick by 1.500 inches wide with a span of 6 inches. The average Kg obtained was 62.6 ksi_in. Since the size ratio, 2.5 (Kg/TYS)², was greater than both the specimen thickness and crack length for longitudinal tests, this Kg value is not a valid K_{ic} value by existing ASIA criteria.
- (f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, R = S_{HI}/S_{max}. "K" represents the Neuber-Paterson theoretical stress concentration factor.
 - (8) Room-remperature three-point bend test. Alternate immeration in 3 1/22 NaCl.

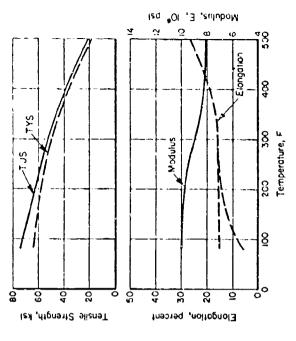


FIGURE 1. SEFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 20% 20% TESS HAND FORGING

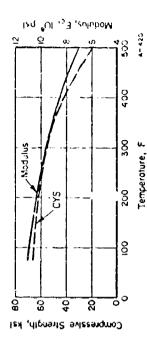
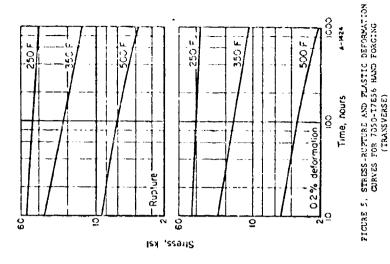


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7050-17550 HAND FORGING



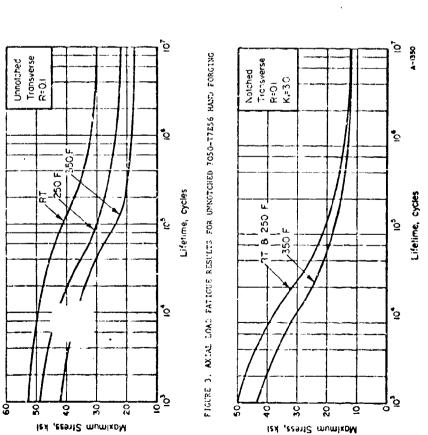


FIGURE 4. AXIAL LOAD PATIGUE RESULTS FOR NOTCHED $(\kappa_{\rm L^{\bullet}}\ 3.0)$ 7050-17656 hand forging

2214-135; Plate (Alcoa 417 Process)

Material Description

5
Alloy 2214 is a high-builty version of 2004 with closer controls or mileon (Alcos 417 recess). The Aires 417 process, it is notifiery colling and applies controls during all vergue of idenfication, it is sectiones for achieving the required perportage without adversely give reversal engineering characteristics of the saterial. The ised in this evaluation was obtained for a Alcoh as a mission and the time the following composition limits.
្សី និង្គី ខ្លែ រូបនៃ និ គ្គី ខ្លែ
Con atto adv
နှင့် စီသာလိုက် ရေသည်။ ရောင့်ရေးရောင်
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200 200
3 / 2 / 2 / 2 / 2 / 2 / 2 / 2 / 2 / 2 /
M4 1 2 2 0
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All
Alloy 2214 is a high-nuilty version of 2014 each conserve conserve and into and salicon (Alcos 417 recess). The Arms 417 process, it is neithing and aprile controls during able to 180 for achieving the require proposed of 180 for achieving the require proposed without advanced material used in this evaluation was obtained for the material. The place within the following composition was obtained for the Alcos as a misting inch-thick
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0 M 4 M 7

Percent	0.50 to 1.2	0.3 aax	3.9 to 5.0	0.40 to 1.2	0.20 to 0.80	0.10 max	0.25 max	6.15	0.15 max	Balance
Composition	Stlicon	Iron	Соррет	Kanganesa	Hagnestun	an leont.	2100	T tentum	Others	Aluminum

Processing and Meat Treating

Specimens were tested in the se-received -f351 temper.

2214-T351 Aluminum Ailoy Data

Thickness: 2 1/4-fach plate

Properties Properties Properties					
### Structural, kai	Properties	14	250	·¬ I	Š
### Structural 1, kai	Tens.con				
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### 1979 1979	(lengitudinel)	8 97	6.1.8	37.6	19.7
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### Structure of the control of the	ongitudinal), percent in	23.8	22.3	24.2	25
Strudinal), percent	(transverse), percent in 2	21.0	23.8	21.0	21
	(longitudinal), percent	34.2	39.7	60.9	71.
Charpy, C. 1b. 10.5 9.9 9.4		27.6	33.5	6.1.9	79
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5.1 U U U (e) U (e) U U (f) U U U U U U U U U U U U U U U U U U U	fr.				
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68 59 59 50 39 39 38 26 36 47 43 47 43 14 21	(9)				
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kst 50 39 39 39 39 30 30 30 30 30 30 30 30 30 30 kst 26 30 30 30 kst 26 21 21 21 21 21 21 32 32 32 32 32 32 32 32 32 32 32 32 32		6.9	\$2	\$6	٦
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ked 43 43 43 ked 24 21 21 21 22 22 22 23 23 24 25 25 25 25 25 25 25 25 25 25 25 25 25	E				
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70 11 31		77	2	21	=
		; ×	=	7.	=

2214-7351 Aluminum Alloy Data (continued)

	-			
		Jemperature, F	ure, F	
Properties	RT	250	350	500
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	N.	3,4	13	14
0.2% plastic deformation, 1000 hr, kai	ΝΑ	22	-	,- 4
Stress Publure (transverse)				
Rustare, 100 hr. kst	Ϋ́Α	577	18	'n
Pupture, 1000 hr. kst	XX	39	13	3.5
Stress Correston (R)				
83% TVS 1000 by maximum	no erache			

13.5 × 10 m in./in./F (68 to 500 F)

Centity

6.101 15/4r.3

1) Values are average of toplicate tests conducted at Battells under the subloci contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of

(b) Roubla-shear pla-type specimen; average of 4 tests.

7, unavailable; NA, not applicable.

9 9

Average of 4 tests.

(e) Six longitudinal and 6 transverse slow-bend apecinens were tracted. Specimen size was 0.750-inch thick by 1.500 inches wide with a span of 6 inches. Average K₁ overlaned uss 45 ksl v.in. in the longitudinal direction and 50.8 ksl: 30. In the transverse direction. Since the size ratio, 1.5 (K₁/TiS)², was greater than both the specimen thickness and crack length in all tests, this K₁ value is not a valid K₁ value by existing ASTM initional.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R=\sum_{j\in J_n}J_n^{j}x$. " K_n " represents the Heuber-Peterson theoretical stress concentiation factor.

(g) Room-temperatura three-point bend test. Alternate immersion in 3-1/22 NaCl.

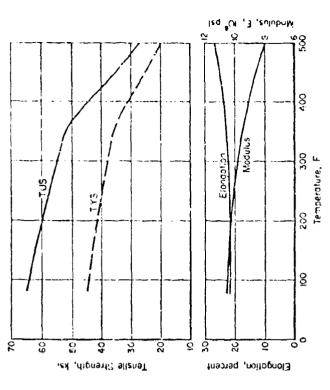


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 2214-1351 PLATE

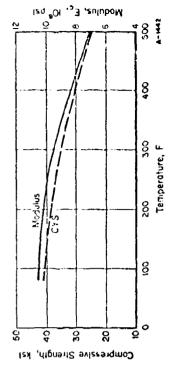
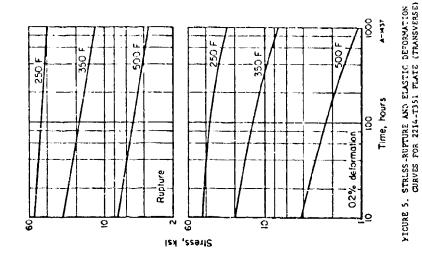
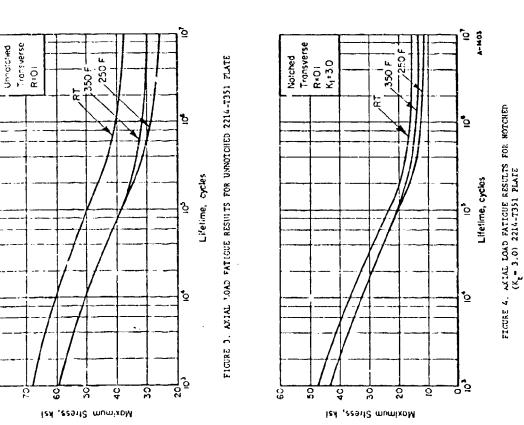


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 2214-1351 PLATE





II-5A:- (V Diffusion Bonded Component (DBHT)

Material Description

The material for this evaluation was supplied by the Air Force Materials laboratory and consisted of pieces sectioned from a helitopser rotor hub. The rotor hub had been formed by diffusion bonding of 1/2-shuh-thick 71-6Ai-4V place. The evaluation material consisted of sections of the hub and lug ends. The material was tested in the astrectived (diffusion bonded heat trasted)(DBMT)

Ti-5Al-4V Data(a)

Condition: Diffusion banding leat treatment Product: Diffusion bonded component

		(ea)	Teaperature,		
sellador.	R	957	530	co.	265
Ten: 10n					
This (transverse), kel	151.3	123.3	p	167.0	7 %
is (Transverse), ksi e (Transverse), hornont in 7 an	143,3	109.3	:2	E. 7	80.9
10° pst	15.9	11.8	ည ည	90, U	0.5
Corpression				}	
	146.3	111.3	ນ	1,75	6 6
Shear (b)	17 \$	15 6	ຍ	15.3	14.5
		,			
SUS (longitudinal), kal SUS (transverse), kal	92.5	(j)	n:	Þ	Þ
Impact (d)	35.9	۵	د	:J	2
,					
V-notch Charpy, Et. 15. (longitudinal)	14.2	D	D	Ŀ	=
(transverse;	15.2	: :	:	ب د	; ;
Fracture Toughness					
Kre (longitudinal), kst/in.	9	Þ	:,		E
KIC (transverse), ks1/in.	٤	2	2		د; د
Axial Fatigue (transverse) (f)					
Unnotched, R = 0.1					
10 cycles, ket 10 cycles, ket	125	125	ລ	36	ສ
10' cycles, ksi	, 09 8	% ¢	- :	۲,	5 ;
Motched, K, = 3.0, R = 0.1		;	,	Ę	,
10' cycles, kei	102	35	;)	5	=
1 2010 (2)	7.	147	D	67) <u> </u>
A CYCLES, KB1	07	30	ä	3	; ;

TI-6/1-4V Data (continued,

		Tem	Temperature, F			
Properties	RI	207	200 200	200	006	
Cree, (transverse)						
0.2% plastic deformation, 100 hr, kal	N Y	ម្	101	\$ 0 P	111	
Original Rubinia (franskatas)	i					
Supture 100 hr. ksi	ź	į.,	111	102	56	
Rupture, 1000 hr, ksf	Ź	ب	110	100	35	
Stress Corresion(8)						
mind hear and 0001 over me	TO CTACKE					

5.7 x 10 x 1n./in./F (58 tc 900 F)

Denof 'v

0.160 lb./in.3

(a) Values are Average of triplicate tests conducted at Buttelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated uning the results of a greater number of tests.

(b) Pouble-shear pin-type specimen.

(c) 5, unavailable; NA, not applicable.

A erage of 4 bes:

g

(e) Quartley of material insufficient for firsture toughness tests.

(f) "Thereforms the algebraic ratio of minimum stress to maximum stress in one cycle; that is, R = Sqin/Smax. "K," represents the Neuber-Puterson theoretical stress concentration factor.

(g) Roce-temperature three-point bend test, Alternate immersion in 3-1/2% NaCi.

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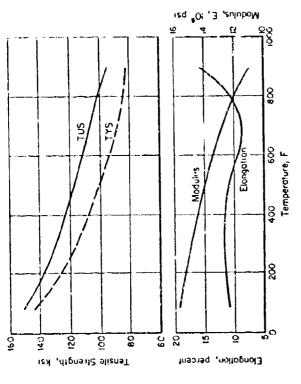


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF TL-6A1-4v DRC (DRHT)

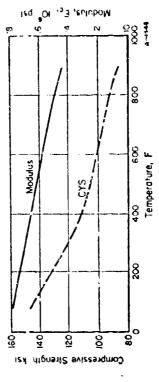


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 71-6A1-4V D&C (DBHT)

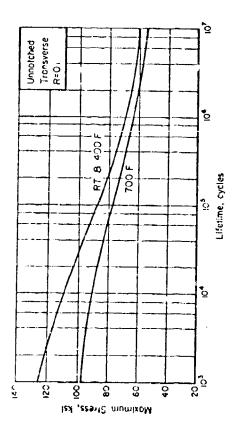


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED TI-6A1-4V DBC (DBHT)

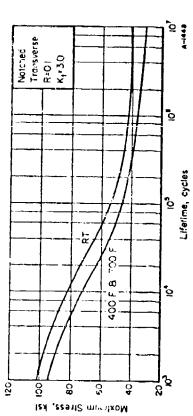


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (Ker 3.0) II-6A1-4V DBC (DBHT)

